WILLIAMS, ARDIS ADA. Effect of Laundering by Professional Services on Selected Flame-Retardant Finished Fabrics. (1971) Directed by: Dr. Pauline E. Keeney. Pp. 72.

Flame-retardant finished fabrics are needed for increased protection from burns associated with flammable cotton fabrics. To be satisfactory for consumer use, flame-retardant finished fabrics must have durability to laundering by professional commercial services.

The purpose of this study was to investigate the effects of professional commercial laundering on the durability of three selected flame-retardant finishes (APO-THPC, THPC-urea-MM, and THPOH-NH_3) on three selected fabrics (100 percent cotton, 70/30 and 50/50 cotton/polyester blends). The specific objectives were to determine differences between: three selected fabrics; unfinished fabrics and flame-retardant finished fabrics; dry-fold and ironing treatments after laundering; and durability of flame-retardant finishes after 0, 5, 10, and 20 launderings.

The fabrics and flame-retardant finishes were prepared by Southern Utilization Research and Development Division of the United States Department of Agriculture for Southern Regional Research Project SM-38. Test fabrics were laundered by two commercial laundries using white wash laundering followed by either dry-fold or ironing treatment. After 0, 5, 10, or 20 launderings, specimens were tested for fire resistance by the American Association of Textile Chemists and Colorists, Vertical Test Method 34-1966. Results were reported as afterflame and afterglow in seconds and char length in inches. Statistically significant differences were determined by analysis of variance.

Observations of burning characteristics and changes in color and hand were reported. The results included changes in color and hand after launderings. The flame-retardant finished fabrics had less afterflame and afterglow than the unfinished fabrics. The unfinished fabrics burned completely, but most flame-retardant finished fabrics had a measurable char length. Many flame-retardant finished fabrics gave off objectionable smoke and odors as they burned.

Several conclusions can be drawn from the experiment. Resistance to fire decreases as the amount of cotton in a blend decreases. The flame-retardant finishes were effective in decreasing the amount of afterflame and afterglow time and in increasing the amount of char length. There were differences among flame-retardant finishes in the effectiveness after commercial laundering. The differences were related to several variables and there was no one most desirable finish. There was a difference in the effectiveness of flame-retardant finishes after laundering by two laundries. There was very little difference in the effect of dry-fold and ironing treatments on the durability of finishes. There was a decrease in fire resistance as the number of launderings increased.

EFFECT OF LAUNDERING BY PROFESSIONAL SERVICES ON SELECTED FLAME-RETARDANT FINISHED FABRICS

by

Ardis Ada Williams

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Approved by

Pauline E. Keeney
Thesis Adviser

APPROVAL PAGE

This thesis has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Thesis Adviser Pauline E. Keeney

Oral Examination Committee Members Pauline E. Keeney

Gail M. Hennis

Eunice M. Deemer

March 25, 1971
Date of Examination

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CHAPTER 1

INTRODUCTION

Emphasis on flame-retardant finished fabrics is based on the prevention of bodily injury due to combustion of apparel and home furnishings fabrics. Since casualties from these injuries rank third behind motor vehicle and household accidents, the suffering, high mortality, and cost associated with extensive burns emphasizes the need for their prevention. This need to prevent bodily injury from burns associated with clothing and home furnishings gives direction to the textiles field.

Protection from burns could be increased if more fabrics were flame-retardant finished. Public opinion, legislation, and the textile industry are all moving toward the day when flame-retardant finished fabrics will be commonly available. As a result of public pressure, research is being conducted on various phases of flame-retardant fabrics.

Research is being done to understand and attempt to solve the many problems associated with the application and use of the flame-retardant finishes. One problem is that of the fiber or fiber blend to be used in fabric construction which would provide optimum satisfaction in the application of flame-retardant finishes. Problems related to the flame-retardant finish include lack of permanency, changed appearance

of the fabric due to the finish, changed hand or feel of the fabrics, decreased fabric performance, and lack of ideal qualities in a single finish. Still another area of concern to both manufacturer and consumer is the additional cost of applying the flame-retardant finish. Further problems result when flame-retardant fabrics are subjected to burning. There are problems of smoke intensity and toxicity, penetrating odor, and possible transfer of heat to adjacent objects. A problem of more concern and importance to the consumer is the care of the fabrics required to maintain effectiveness of the finish.

As each flame-retardant finish is developed, it is tested for durability to home, commercial, or industrial laundering procedures. There is differentiation between these three laundering procedures as well as within each procedure. In order to accelerate research on treated fabrics, laboratory test methods have been developed to simulate the effect of home, commercial, or industrial laundering. Laboratory tests are designed as an attempt to duplicate results from actual service, but there is some question as to whether this is accomplished. Most of the research on flammability reported is the result of such laboratory test methods. No reported research could be cited pertaining to the effectiveness of professional commercial laundering services on the serviceability of flame-retardant finished fabrics.

STATEMENT OF THE PROBLEM

This study was designed to investigate the effect of laundering by professional commercial services on selected flame-retardant finished

fabrics. In order to be designated as durable, the finish must retain the fire resistant characteristics after numerous launderings. Various processes within the commercial laundry procedure may affect the durability of the finish chemically or physically. The flame-retardant finish may be affected chemically by the soap, synthetic detergent, builder, bleach, optical brightener, or acid sour. The finish may be affected physically by water, mechanical agitation, or heat--especially ironing.

The major purpose of this study was to investigate the durability after professional commercial laundering of selected flame-retardant finishes as applied to selected fabrics. The specific objectives of the study were:

1. To determine differences in fire resistance characteristics after laundering of three selected fabrics: (a) 100 percent cotton, (b) 70/30 cotton/polyester blend, and (c) 50/50 cotton/polyester blend.

2. To determine differences in fire resistance characteristics after laundering of fabrics treated with three selected flame-retardant finishes: (a) APO-THPC, (b) THPC-urea-MM, and (c) THPOH-NH_3.

3. To determine differences in fire resistance characteristics of selected finishes and fabrics as affected by dry-fold and ironing laundering treatments. The two treatments were used as a means of indicating the effect of heat upon the durability of the finishes.

4. To determine differences in fire resistance characteristics of the selected fabrics and fire-retardant finishes before laundering and after 5, 10, and 20 launderings.

The assumption was made that the flame-retardant finishes increase the fire resistance of the fabrics. Because the flame-retardant finishes were applied rather than being an inherent part of the fibers, some of the flame-retardant finish may have been lost due to the chemical and physical processes of laundering. The assumption was made that each repetition of the professional commercial laundering was the same in temperature of water, strength of washing compounds, duration of process, and agitation of mechanism as reported by the laundries. Also, it was assumed that each ironing treatment was done at the same temperature for the same length of time.

The following hypotheses were established and tested:

1. There are no significant differences in fire resistance characteristics in the effectiveness of the flame-retardant finish as the proportion of cotton in the fiber blend decreases among 100 percent cotton fabric, 70/30 cotton/polyester blend fabric, and 50/50 cotton/polyester blend fabric.

2. There are no significant differences in fire resistance characteristics in the effectiveness of different flame-retardant finishes among three selected finishes after commercial laundering.

3. There are no significant decreases in fire resistance characteristics in the effectiveness of flame-retardant properties when the commercial laundering is concluded by the ironing treatment rather than the dry-fold treatment.

4. There are no significant decreases in fire resistance characteristics after 5, 10, and 20 launderings.

DEFINITION OF TERMS

The following definitions have been included for clarification of terms used in relation to the laundering and fire resistance of fabrics and finishes.

Flame-Retardant Finish. This refers to an applied finish which appreciably slows down combustion once the source of heat is removed.[1]

Fire Resistance. According to the American Association of Textile Chemists and Colorists, "fire resistance is defined as resistance to flaming, glowing, and smoldering."[2]

Afterflame. The American Association of Textile Chemists and Colorists defines afterflame as "duration of flaming of the specimen, from the time the burner flame is removed."[3]

Afterglow. This is defined by the American Association of Textile Chemists and Colorists as "the time the specimen continues to glow after it has ceased to flame."[4]

Char Length. The char length is defined by the American Association of Textile Chemists and Colorists as "the distance from the

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[1]R. Aenishanslin, "Flame-Retardant Finishes for Cellulosic Fibers," CIBA Review, 1969/4 p. 35.

[2]American Association of Textile Chemists and Colorists, Technical Manual. Vol. 45, North Carolina: AATCC, 1969, 208. (The Association is hereafter referred to as AATCC.)

[3]AATCC, Technical Manual. p. 208.

[4]AATCC, Technical Manual. p. 208.

edge of the specimen exposed to the flame to the end of the tear made through the center of the charred area."[5]

Commercial Laundering. This is defined as professional laundering done with the white wash procedure used for cotton and linen involving two or three sudsings, bleach or optical brightener, three rinsings, and acid sour followed by extraction of water and either dry-folding after tumble drying or ironing treatment.

Break. This is defined as a step in the commercial laundering procedure.

Acid Sour. This is defined as an acid salt added to the final laundering step to neutralize alkalinity from the soap or detergent.

APO-THPC. For purpose of brevity these letters signify the chemical compound tris-(1-aziridinyl) phosphine oxide tetrakis (hydroxymethyl) phosphonium chloride.

THPC-urea-MM. For purpose of brevity these letters signify the chemical compound tetrakis (hydroxymethyl) phosphonium chloride urea methylolmelamine.

THPOH-NH_3. For purpose of brevity these letters signify the chemical compound tetrakis (hydroxymethyl) phosphonium hydroxide ammonia cure.

BEL. For purpose of brevity these letters signify "burned entire length." This is the result of total consummation of fabric by flame and glow without char length remaining.

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[5]AATCC, Technical Manual. p. 208.

CHAPTER 2

REVIEW OF LITERATURE

Fire resistant finishes were developed as early as 1735. World War II increased the need for weatherproof, flame-retardant, and moth and mildew resistant finished fabrics. In 1945, the first legislation was passed regarding the sale of "fabrics more flammable than cotton in its natural state."[1] Since then Public Law 88, known as the Flammable Fabrics Act of 1953, was passed regarding standards for flammable fabrics. It was aimed at preventing the sale of dangerously flammable fabrics such as the "torch sweaters" which had caused much immediate public reaction. Public Law 88 was amended in 1967 to include broader aspects of flammability. The amended Act of 1967 gives the Secretary of Commerce authority to "conduct research into the flammability of products, fabrics, and materials."[2]

Much work has been done by the United States Department of Agriculture, Southern Utilization Research and Development Division, in developing flame-retardant finishes. Since the finishes and fabrics used in this study were prepared as part of the Cooperative State Research Service in Cotton Marketing, Project SM-38, the literature

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[1] State of California, Chapter 8, Part 3 of Division 13 of Health and Safety Code, 1945.

[2] U. S. Congress, Public Law 90-189, 90th Congress, S. 1003, December 14, 1967.

reviewed is primarily from the research of the Southern Utilization Research and Development Division Laboratory.

Development of Flame-Retardant Finishes for Cellulose

The concern with flame-retardant finishes for all cotton and cotton blend fabrics is a result of the chemical and physical nature of burning cellulosic fibers. Schuyten, Weaver, and Reid determined that when temperatures of only 300° F. or more are applied to cellulose, it decomposes into gaseous, liquid, tarry, and solid products. The gases ignite, support the flame, and further the pyrolytic decomposition until a carbonaceous residue remains. This residue then oxidizes and glows until the organic matter is consumed.[3]

The primary functions of flame-retardant finishes are to impede combustion after removal of the heat source and to eliminate the afterglow of the carbon residue. Other desirable qualities of flame-retardant finished textiles are durability to laundering and/or dry cleaning, retention of high tensile strength, flat abrasion resistance, controlled residual shrinkage, and colorfastness of dyes. Qualities of importance to the consumer are soft hand, lack of odor, mildew resistance, non-allergenic, non-toxic, and low cost.[4]

Flame-retardant finishes may be grouped into two major classifications. The group of non-durable additive finishes based on

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[3]H. A. Schuyten, J. W. Weaver, and J. D. Reid, "Some Theoretical Aspects of the Flameproofing of Cellulose," Advances in Chemistry Series, No. 9, (June, 1954), p. 8.

[4]Henry J. Franklyn, "Some of the Industrial Flame-Retardant Finishes for Textiles," American Dyestuff Reporter, LII (June 10, 1963), p. 455.

water-soluble salts is unsatisfactory in that the finish must be renewed after each laundering. The second group of finishes is more durable as a result of the chemical reaction between the cellulose molecule of the cotton fiber and the flame-retardant finish.[5]

Theoretically, the flame-retardant finish acts as a catalyst in bringing about dehydration of the cellulose by Lewis acid reaction through carbonium ion mechanism.[6] The flame-retardant finish must remain stable until temperatures approach that of decomposing cellulose, then react to dehydrate catalytically the cellulose and reduce the flammability of the volatile products of decomposition.[7]

Gottlieb has stated that durability is achieved by the use of organic compounds which form insoluble polymers within the fiber. The flame-retardant compounds are reacted with the hydroxyl groups of the cellulose molecule. Flame-retardant compounds are based on organic phosphorus and/or nitrogen molecules with unsaturated allyl or vinyl groups capable of polymerization.[8]

Three of the flame-retardant finish compounds that will be further discussed are tetrakis (hydroxymethyl) phosphonium chloride-

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[5]Irvin M. Gottlieb, "A Theory of Flame-Retardant Finishes," Textile Research Journal, XXVI (February, 1956), p. 159.

[6]H. A. Schuyten, J. S. Weaver, and J. D. Reid, "Effect of Flame-proofing Agents on Cotton Cellulose," Industrial and Engineering Chemistry, XLVII (July, 1955), p. 1433.

[7]Gottlieb, "A Theory of Flame-Retardant Finishes," p. 159.

[8]Gottlieb, "A Theory of Flame-Retardant Finishes," p. 160.

urea-methylolmelamine (THPC-urea-MM), tris-(1-aziridinyl) phosphine oxide tetrakis (hydroxymethyl) phosphonium chloride (APO-THPC), and tetrakis (hydroxymethyl) phosphonium hydroxide with ammonia cure (THPOH-NH_3).

THPC-urea-MM. Studies of aminized cotton by Reeves and Guthrie of the Southern Regional Research Laboratory in the early 1950's led to findings that tetrakis (hydroxymethyl) phosphonium chloride (THPC) would make the aminized cotton fabric flame-retardant. Later the aminization step was eliminated and THPC reacted with methylolmelamine to make cotton fabric permanently flame-retardant.[9]

In carrying out this research phosphine was reacted with formaldehyde and hydrochloric acid to make THPC. The THPC compound is crystalline, soluble in water and in many organic solvents including alcohols. THPC is made effective by combining with other compounds. The THPC compound forms polymers with melamine and methylolmelamines to give properties of crease resistance. Trimethylolmelamine is combined with THPC to increase solubility properties. Urea is used to tie up the free hydrochloric acid given off by the THPC during polymerization. Triethenolamine is used to stabilize the solution at room temperature. The finish is applied in a conventional pad, dry, cure, wash, softening process.[10]

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[9]Wilson A. Reeves and John D. Guthrie, "THPC, New Flame-Resistant Treatment, Is Permanent and Effective," Textile World, CIV (February, 1954), p. 101.

[10]Reeves and Guthrie, "THPC, New Flame-Resistant Treatment," p. 101.

urea-methylolmelamine (THPC-urea-MM), tris-(1-aziridinyl) phosphine oxide tetrakis (hydroxymethyl) phosphonium chloride (APO-THPC), and tetrakis (hydroxymethyl) phosphonium hydroxide with ammonia cure (THPOH-NH_3).

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[10]Reeves and Guthrie, "THPC, New Flame-Resistant Treatment," p. 101.

Reeves and Guthrie have further reported fabric properties of THPC finished fabrics to include crease resistance, rot and mildew resistance, and very little loss in breaking strength, but some loss of tear strength which can be overcome by softeners.[11] The THPC finish was good with vat-dyed fabrics and could be used as a bonding agent for pigment-dye.[12]

According to Reeves and Guthrie, THPC finished fabrics laundered following Federal Specification CC-T-191 b with Igepon T followed by a laundry sour passed the vertical flame test after 15 launderings.[13] Guthrie, Drake, and Reeves stated that the flame-retardant was durable to washing with synthetic detergents.[14] There was about 15 to 20 percent loss in resin when the flame-resistant fabric was boiled in soap and soda solution for three hours. Permanence was increased by increasing the amount of resin add-on and varying the finish formulation.[15]

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[11]Reeves and Guthrie, "THPC, New Flame-Resistant Treatment," p. 176.

[12]K. M. Decossas and others, "Flame-Resistant Cottons," Textile Industries, CXXX (July, 1966), p. 128.

[13]Reeves and Guthrie, "THPC, New Flame-Resistant Treatment," p. 102.

[14]John D. Guthrie, George L. Drake, and Wilson A. Reeves, "Application of the THPC Flame-retardant Process to Cotton Fabrics," American Dyestuff Reporter, XLIV (May 9, 1955), p. 331.

[15]Reeves and Guthrie, "THPC, New Flame-Resistant Treatment," p. 102.

Another important property of the fabrics treated with THPC was good glow resistance. Guthrie and others reported that the afterglow of such fabrics was usually less than two seconds.[16]

APO-THPC. The tris-(1-aziridinyl) phosphine oxide (APO) flame-retardant finish was developed by the Southern Regional Research Laboratory in reaction with THPC and was designated, APO-THPC. Reeves and others prepared APO by reacting ethylenimine with phosphorus oxychloride in an inert solvent such as benzene. It was then distilled and purified. The APO compound is crystalline, soluble in water and a number of organic solvents, but has limited solubility in petroleum ether.[17] APO is a hazardous substance and should be handled with care to prevent contact with the skin.[18]

APO reacts and polymerizes by addition via ring opening. Since APO has three functionally attached groups it can be used for multiple finishes. Crosslinking can occur with cotton and with other compounds. It has been used with additional wash-wear finishes, with oil and water repellent compounds, with dyes, and with embossing techniques.[19]

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[16]Guthrie, Drake, and Reeves, "Application of the THPC Flame-retardant Process to Cotton Fabrics," p. 332.

[17]Wilson A. Reeves and others, "Flame Retardants for Cotton Using APO- and APS- THPC Resins," Textile Research Journal, XXVII (March, 1957), p. 260.

[18]Homer K. Gardner, Jr., G. L. Drake, Jr., and N. B. Knoepfler, "Applying a Durable Flame Retardant With Inplant Equipment," Hospitals, XXXVII (November 16, 1963), p. 124.

[19]R. M. Perkins, G. L. Drake, Jr., and W. A. Reeves, "APO - A Versatile Textile Chemical," ARS 72-32, December, 1964, p. 4.

When APO and THPC were reacted, a complex, insoluble, highly crosslinked, flame-resistant thermosetting resin was formed. The reaction increased the stability of the solutions, made the amount of add-on lower as a result of the mutual contribution of phosphorus, and increased the durability to alkaline washing.[20] Decossas and others report that the formation of formaldehyde during application causes several problems with the APO-THPC finish. Toxic free formaldehyde may be given off during the processing of the fabric. After processing, the fabric is inert and non-toxic.[21]

Decossas reported that fabrics finished with APO-THPC had good wrinkle resistance, rot and mildew resistance, and shrinkage resistance. The hand and appearance of APO-THPC finished fabrics were good. There was little change in appearance, hand, and texture as a result of low resin add-on.[22] Drake found some loss of breaking strength which was improved by use of softeners as an after treatment.[23] Decossas also reported that the APO-THPC was an expensive finish. It was thought as production of the finish increased, the cost might decrease.[24]

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[20]George L. Drake, Jr., John V. Beninate and John D. Guthrie, "Application of the APO-THPC Flame Retardant to Cotton Fabric," American Dyestuff Reporter, L (February 20, 1961), p. 133.

[21]K. M. Decossas and others, "Flame-resistant Cottons," Textile Industries, XXX (July, 1966), p. 133.

[22]Kenneth M. Decossas, "Costing the APO-THPC Finish," Textile Industries, XXV (April, 1961), p. 162.

[23]George L. Drake, Jr., John V. Beninate and John D. Guthrie, "Application of the APO-THPC Flame Retardant to Cotton Fabric," p. 133.

[24]Decossas, "Costing the APO-THPC Finish," p. 162.

Drake, Beninate, and Guthrie found fabrics treated with APO-THPC to have satisfactory durability to laundering. After 15 launderings using fluoride sour according to Federal Specification CCC-T-1916 No. 5556, the APO-THPC finished fabric, with 15 percent resin add-on, had a char length less than three inches. The fabric strength was not affected by chlorine bleach.[25]

THPOH-NH_3. Development of the tetrakis (hydroxymethyl) phosphonium hydroxide ammonia cure (THPOH-NH_3) finish by Beninate and others was the result of an attempt to find a flame-retardant that does not liberate hydrochloric acid (HCl) during the finish application as did THPC. The THPOH-NH_3 finish was prepared by adding sodium hydroxide to THPC. An equilibrium mixture of THPOH and tris (hydroxymethyl) phosphine, (THP) was formed. The finish was then applied, dried, and chemically fixed in the cellulosic material by exposure to ammonia gas, to form water insoluble polymers in the cellulose.[26]

Beninate and others have reported the properties of fabrics finished wth THPOH to have little change in hand, minimal losses of breaking and tear strength, and little or no yellowing when bleached with sodium hypochlorite solution and then scorched. The THPOH treated fabrics were also reported to be durable to home laundering conditions and remained flame resistant.[27]

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[25]Drake, Beninate, and Guthrie, "Application of the APO-THPC Flame Retardant to Cotton Fabric," p. 130.

[26]Beninate and others, "Better Flame Resistant Finish for Cottons," Textile Industries, CXXXI (November, 1967), p. 110-112.

[27]Beninate and others, "Better Flame Resistant Finish for Cotton," p. 118.

Effects of Laundering

Laundering involves water, mechanical agitation, and various additives. The nature of the water, its hardness or softeness, the minerals contained, and the temperature of the water affect its property of solvency as a cleaning medium. The mechanical agitation of textiles is necessary to aid in penetration of the cleaning medium and breaking up of soil particles. Mechanical agitation also acts as an abrasive force on the surface of the fabric. Additives include soaps, detergents, builders, bleaches, optical whiteners, fabric softeners, and acid sours. All of these materials and forces act and interact on fabrics during laundering.

Water. Reeves determined that alkali or alkaline earth metal ions such as calcium and magnesium can be picked up by the treated flame-retardant fabric during laundering resulting in decreased flame resistance. The pick up occurs through ion exchange and precipitation with phosphates from detergents and fatty acids from soaps. The flame-retardant in the fabric and the amount of metal ions in the water influence the amount of phosphate picked up.

> "Calcium and magnesium soaps in fabric can cause erroneous interpretations about the durability of flame retardants when flame tests are used to measure durability. The adverse effects of these foreign materials may be removed by rinsing the laundered fabric occasionally in dilute acid."[28]

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[28]Wilson A. Reeves, "Some Factors Influencing the Effectiveness of Durable Phosphorus-Containing Flame Retardants for Cellulosic Textiles" (paper presented at the 160th National ACS Meeting, Division of Cellulose, Wood, and Fiber Chemistry, Chicago, Illinois, September 13-18, 1970) p. 14.

Soaps and Detergents. Perkins, Drake, and Reeves determined that hardness or softness of water and the use of soap or detergent may affect the flame-resistance of specimens. The APO-THPC samples passed the vertical flame test after 10 launderings when washed in hard water with soap. When a detergent was used the sample failed the flame test. No serious loss of flame resistance resulted when soft water with either soap or detergent was used.[29] Brysson also concluded that even moderately hard water with detergents or "built" soaps can cause insoluble calcium phosphate build-up.[30]

Bleach. Daigle and others found that hypochlorite bleach adversely affected most THPC flame-retardant finishes. After 20 launderings the APO-THPC finish passed the vertical flame test.[31]

Temperature. Reeves suggested that heat from ironing decreases the effectiveness of some flame-retardants as a result of hydrolysis of the ester groups of alkyl phosphonates at ironing temperatures.[32]

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[29]R. M. Perkins, G. L. Drake, Jr., and W. A. Reeves, "The Effect of Laundering Variables on the Flame Retardancy of Cotton Fabrics" (paper presented at the American Oil Chemists' Society Symposium, New Orleans, Louisiana, April 26-30, 1970) p. 10-11.

[30]Ralph J. Brysson, Biaggio Piccolo, and Albert M. Walker, "Calcium-Phosphorus Deposition During Home Laundering" (New Orleans: Southern Utilization Research and Development Division, MTST-55) p. 3-4. (Mimeographed.)

[31]D. J. Daigle, Wilson A. Reeves, J. V. Beninate, and George L. Drake, Jr. "The Effect of Hypochlorite Bleach on Flame Retardant Finishes Based Upon THPC" (New Orleans: Southern Utilization Research and Development Division, MTST-34) p. 7. (Mimeographed.)

[32]Wilson A. Reeves, "Some Factors Influencing the Effectiveness of Durable Phosphorus-Containing Flame Retardants for Cellulosic Textiles," p. 14.

Fabrics

Simms has reported three fabric properties important to the hazardousness of the fabric. The properties are the heat output of the burning fabric, the fabric weight per unit area, and the ignition or melting temperature. Simms further states the most important property is weight per unit area as this influences the ignition time needed and the rate of spread of flame.[33]

LeBlanc states that polyester has a higher heat of combustion or point at which combustion is self-sustaining than cotton. The thermoplastic fibers have different heat reaction properties including melting and dripping.[34]

Simms has stated that "mixtures of (thermoplastics) with natural fibres may burn rapidly because the natural fibre holds the synthetic fibre in position."[35]

Summary

A review of literature revealed some laundering durability tests had been performed on flame-retardant finished fabrics. Most of the testing was done by means of laboratory tests devised to simulate commercial laundering or home laundering procedures. No evidence was found of testing following the services of professional commercial laundries.

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[33]D. L. Simms, "Fire Hazards of Fabrics," Textile Institute and Industry, I (September, 1963), p. 11-12.

[34]R. Bruce LeBlanc, "The Present Status of Fire Resistance," Textile Chemist and Colorist, II (April 8, 1970), p. 125.

[35]D. L. Simms, "Fire Hazards of Fabrics," p. 12.

CHAPTER 3

PROCEDURE

The fabrics used in this study were obtained from the Southern Utilization Research and Development Division, United States Department of Agriculture, New Orleans, Louisiana. The fabrics were prepared with the flame-retardant finishes according to the specifications of the Southern Utilization Research and Development Division. This study and the fabrics used are part of the Southeast Regional Project of the USDA, Project SM-38.

Description of Fabrics

The 12 fabric and flame-retardant finish combinations prepared were:

1. Samples of 100 percent cotton, 70/30 cotton/polyester blend, and 50/50 cotton/polyester blend without flame-retardant finish.

2. Samples of 100 percent cotton, 70/30 cotton/polyester blend, and 50/50 cotton/polyester blend finished with APO-THPC. The processing procedure used was padding by two dips, two nips through 30 percent solids APO-THPC solution under tight squeeze roll pressure. The wet pick-up was between 70 and 80 percent. The fabrics were frame dried for three minutes at 85° C., then cured on the frame for four minutes at 140° C. They were then washed on a jig and frame dried.

3. Samples of 100 percent cotton, 70/30 cotton/polyester blend, and 50/50 cotton/polyester blend were finished with THPC-urea-MM. The processing procedure used was padding through a 40 percent solids solution of THPC-urea-MM, two dips, two nips, under tight squeeze roll pressure. Wet pick-up was 70 to 85 percent. The fabrics were dried at 85° C. for three minutes on a tenter frame. They were frame cured for three minutes at 150° C. They were then washed on a jig and frame dried.

4. Samples of 100 percent cotton, 70/30 cotton/polyester blend, and 50/50 cotton/polyester blend were finished with THPOH-NH_3. The processing procedure used was padding through a 40 percent solids solution of THPOH with two dips, two nips, under tight squeeze roll pressure. Wet pick-up was 80 to 90 percent. The fabrics were tenter frame dried at 85° C. to a moisture content of 20 percent. The fabrics were then exposed to ammonia gas (NH_3) in an enclosed jig for 10 ends. They were then washed on a jig and frame dried.

Preparation of Test Swatches

The test fabric samples were prepared for the laundering treatments by cutting with pinking shears into 8 inch X 12 inch pieces in the warp direction. The fabrics were marked with code symbols by means of laundry marking equipment for identification after treatment. Test sheets to facilitate laundering were prepared by randomized placement of the 12 flame-retardant and control fabrics, then double stitched together into single sheets (Figure 1). Three sheets were prepared for each laundering treatment, including three withheld from any treatment used as control fabrics.

10	1	9	12
7	6	4	11
2	5	8	3

Figure 1. Examples Showing Randomized Placement of Test Fabrics

Laundering Procedures

Two laundries, for the purpose of replication, were selected on the basis of willingness to cooperate and their previous experience in conducting research. They were members of the American Institute of Laundering and followed set procedures throughout the treatment. The two laundries varied from each other in the number of sudsings and the use of bleach or whitener.

The procedure of Laundry A was two breaks of sudsing for six minutes at 180° F. with a built synthetic detergent, one break with dry organic bleach for six minutes at 180° F., three rinse breaks of two minutes each; one at 160° F., one at 140° F., and one at 120° F., followed by a laundry sour and fabric softener for three minutes at 120° F.

The procedure of Laundry B included one break of alkaline builder, two breaks of tallow soap and alkaline builder for five minutes each at 160° F., a rinse of five minutes with laundry whitener and anti-chlor at 160° F., two rinses for five minutes each at 160° F. and the second at 140° F., and one rinse for three minutes at 120° F., followed by a three minute rinse with acid sour and cationic softener.

Both laundries used extraction followed by tumble drying or ironing as specified for each test sheet. The test fabrics were withdrawn after 5, 10, or 20 launderings. The launderings were on successive days of a five day week with one laundering treatment given each day. After laundering, the fabrics were prepared for fire resistance testing.

The fire resistance testing was done according to American Association of Textile Chemists and Colorists (AATCC) Vertical Flame Test Method 34-1966.[1] The purpose of this test was to measure the fire resistance of treated fabrics. Specimens were cut 2 3/4 inches by 10 inches, conditioned, and placed in aluminum holders ready for testing in a fire resistance test cabinet. The test was performed by exposing 3/4 inch of 1 1/2 inch bunsen burner flame on one edge of the fabric for 12 seconds at which time the flame was removed. The time the fabric continued to support combustion was observed and measured as the afterflame time. The time after burning ceased and the glow continued

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[1]American Association of Textile Chemists and Colorists, Technical Manual. Vol. 45, North Carolina: AATCC, 1969, p. 209.

was observed and measured as the afterglow time. The specimen was then removed from the cabinet and the frame in order to be prepared for char length measurement by making a small snip 1/4 inch from the outside edge and 1/4 inch from the lower edge. A weight was inserted in accordance with the weight of the fabric as determined from the table given in the testing procedure. The opposite lower corner was grasped to raise the specimen for the weight to clear the table surface and cause a tear in the damaged area of the specimen. The length of the tear was measured and reported as the char length.

Treatment of Data

The fabrics were observed before, during, and after laundering for changes in color and hand. Changes were recorded. Burning characteristics were observed and recorded to aid in the explanation of the statistical data.

The data from the recorded fire resistance characteristics of afterflame, afterglow, and char length were analyzed statistically with analysis of variance to determine significance of differences. Data were analyzed separately for the three fabrics and four finishes before commercial laundering. After commercial laundering the primary analysis of variance included fabrics, finishes, treatments, laundries, and launderings.

CHAPTER 4

PRESENTATION OF DATA

The major purpose of this study was to investigate the durability after professional commercial laundering of selected flame-retardant finishes as applied to selected fabrics. The durability of the flame-retardant finish was determined by the fire resistance characteristics of afterflame, afterglow, and char length as measured by the American Association of Textile Chemists and Colorists (AATCC) Vertical Flame Test Method 34-1966.

The fabrics used for this study were prepared by the Southern Utilization Research and Development Division, USDA, as part of the Southeastern Regional Project of the USDA, Project SM-38. The fabrics included 100 percent cotton, 70/30 cotton/polyester blend, and 50/50 cotton/polyester blend. The flame-retardant finishes applied to the fabrics were APO-THPC, THPC-urea-MM, and THPOH-NH_3. One set of fabrics had no finish for purposes of comparison.

The flame-retardant finished test fabrics were laundered by two professional commercial laundries. After laundering, the fabrics were either tumble dried, designated as dry-fold treatment, or given an ironing treatment as planned for each test sheet. Samples were withdrawn for fire resistance testing after 0, 5, 10, or 20 launderings.

The results of the study will be reported in two parts. The first section is a report of performance observations. Observations were made of changes in appearance in terms of color and hand before, during, and after laundering. Observations were also made of the burning characteristics of a selected fabric from within each category of variation. Since these are subjective observations they are reported in general terms.

The second section of the presentation of data is the statistical analysis of measurements obtained by the AATCC Vertical Test Method 34-1966. An analysis of variance was used to statistically analyze the afterflame, afterglow, and char length measurements. Data for unlaundered control fabrics were treated separately to determine significance of differences in the three fabrics and four finishes prior to laundering. The primary analysis of variance for fire resistance characteristics after commercial laundering was 3 fabrics X 4 finishes X 2 treatments X 2 laundries X 3 times laundered X 4 replications. Further analyses of variance were made to determine the differences of the unfinished fabrics and finished fabrics after laundering. The analysis of variance for the unfinished fabrics was 3 fabrics X 2 treatments X 2 laundries X 3 times laundered X 4 replications. The analysis of variance for the finished fabrics was 3 fabrics X 3 flame-retardant finishes X 2 treatments X 2 laundries X 3 times laundered X 4 replications. Both the unlaundered control data and the laundered test data are included on Tables 1, 2, 4, 6, 7, 8, and 9 and Figures 2, 3, 4, 5, 6, 7, and 8 for purposes of comparison.

The lack of char length which resulted when a fabric was completely consumed by burning is reported as BEL, burned entire length. It was given the numerical value 0.0.

FINDINGS RELATED TO PERFORMANCE OBSERVATIONS

Durability to commercial laundering may be divided according to retention of desirable appearance qualities and retention of fire resistance qualities. The experimental fabrics, as flame-retardant finished by the mill for use in this study, were not given a final washing and softening process. As a result, there was some loss of excess finish after the early launderings. After the first laundering, Laundry A complained of an obnoxious odor given off during washing. The Laundry also reported that the odor was not as noticeable after further launderings. There were distinct differences in the appearance and hand of the fabrics treated with the various flame-retardant finishes before and after laundering. Characteristics related to burning but not measurable were also noted and reported.

Observed Changes in Color

One of the desirable appearance qualities of white fabrics is retention of whiteness after laundering. The application of the flame-retardant finishes changed the whiteness of the fabrics when compared to the unfinished fabric of the same fiber content. Also, with repeated commercial launderings there were further changes in color, both from the original unfinished fabric and from the finished fabric before laundering.

Before laundering, there were slight color differences among the unfinished fabrics. The two blended fabrics were a brighter white than the 100 percent cotton fabric.

The author classified the observed changes in color and arbitrarily selected a five point scale for the purpose of simplifying the reporting of color changes (Table 1). The classification scale was:

5 - No change in whiteness

4 - Slight change in whiteness

3 - Moderate change in color

2 - Noticeable color change

1 - Objectionable color change

When noticeable color changes occurred, a few were toward yellow and others were toward gray. Differences were noted in the same fabric processed by the two laundries. There were visible differences between the dry-fold and ironing treatments for some of the fabrics.

The most objectionable color changes were those of the APO-THPC finished 100 percent cotton and 50/50 cotton/polyester blend fabrics processed by Laundry B. These fabrics were a very dingy gray after 5 launderings. The whiteness improved with additional launderings.

The finish that showed the least color change after laundering was THPOH-NH_3. The THPC-urea-MM was the whitest before laundering, but decreased in whiteness after laundering. The APO-THPC finish was the least white on all fabrics before laundering and generally did not improve with laundering.

Table 1

Classification of Observed Color Changes

Fabrics / Launderings	Unfinished					APO-THPC					THPC-urea-MM					THPOH-NH_3				
	Dry-fold Laundry			Ironed Laundry		Dry-fold Laundry			Ironed Laundry		Dry-fold Laundry			Ironed Laundry		Dry-fold Laundry			Ironed Laundry	
	0*	A	B	A	B	0*	A	B	A	B	0*	A	B	A	B	0*	A	B	A	B
100% cotton																				
0	5					3					5					4				
5		5	5	5	5		3	1	2	2		5	5	5	5		5	4	5	5
10		5	4	5	5		3	3	3	3		4	3	5	4		5	5	5	5
20		4	4	5	5		2	2	3	4		4	4	4	4		5	5	5	5
70/30 blend																				
0	5					4					5					5				
5		5	5	5	5		4	4	4	4		5	5	5	5		5	5	5	5
10		5	5	5	5		4	4	3	4		5	4	5	4		5	5	5	5
20		4	4	5	5		4	4	3	5		4	4	4	5		5	5	4	4
50/50 blend																				
0	5					4					5					4				
5		5	5	5	5		4	1	3	3		5	5	5	5		5	5	5	5
10		5	5	5	5		2	4	3	3		5	4	5	4		5	5	5	5
20		4	5	4	5		2	3	3	4		4	3	3	5		4	5	3	5

Classification by author

5 - No change in whiteness
4 - Slight change
3 - Moderate change
2 - Noticeable change
1 - Objectionable change

*Unlaundered control

Observed Changes in Hand

Hand is defined as the feel or texture of a fabric. In order to make a flame-retardant finish effective and durable, the amount of finish applied to the fabric must be increased. The weight of the applied finish tends to make the fabric stiff and heavy. All of the finishes made each of the fabrics heavier, although there was variation in weight and stiffness.

These fabrics as prepared for experimental purposes were not given a final washing and softening treatment of the type used by the manufacturer for consumer products. The omission of this softening treatment explains some of the distinct softening from the initial stiffness.

The hand of the fabrics was observed and a system was set up by the author to classify the resulting changes in hand (Table 2). The classifications were:

5 - Soft

4 - Pliable

3 - Medium

2 - Firm

1 - Stiff

There was a general difference in hand between the dry-fold treated fabrics and the ironed fabrics. The dry-fold treated fabrics were softer due to the action of tumble drying. Fabrics with the ironing treatment were firmer. No difference in hand was observed between the fabrics processed by the two laundries. There were two

Table 2

Classification of Observed Changes in Hand

Fabrics	Unfinished			APO-THPC			THPC--urea-MM			THPOH-NH_3		
Launderings	0*	Dry-fold	Ironed	0*	Dry-fold	Ironed	0*	Dry-fold	Ironed	0*	Dry-fold	Ironed
100% cotton												
0	5			2			1			2		
5		5	5		5	3		5**	2		5	2
10		5	5		5	3		5	3		5	3
20		5	5		5	4		5**	3		5	5
70/30 blend												
0	5			2			1			2		
5		5	5		2	2		1	1		3	3
10		5	5		3	2		1	1		5	3
20		5	5		5	3		2	2		5	3
50/50 blend												
0	5			2			1			4		
5		5	5		5	4		4	2		5	5
10		5	5		5	5		4	2		5	5
20		5	5		5	5		5	3		5	5

Classification by author
- 5 - Soft
- 4 - Pliable
- 3 - Medium
- 2 - Firm
- 1 - Stiff

*Unlaundered control

**Appearance difference noted between two laundries

differences in appearance noted for the THPC-urea-MM finish 100 percent cotton as processed by the two laundries. After 5 and after 20 launderings, there were distinct wrinkles retained in the fabrics processed by Laundry A.

The unfinished fabrics were soft before and after laundering. After laundering, the THPOH-NH_3 finished fabrics had the most desirable hand followed by the APO-THPC finished fabrics. The THPC-urea-MM finished fabrics were extremely stiff before laundering and remained the least soft after laundering. The 100 percent cotton and 50/50 cotton/polyester blend were softer with the dry-fold treatment. The 70/30 cotton/polyester blend resulted in no difference between the dry-fold and ironing treatments.

Observed Burning Characteristics

The flame-retardant finishes definitely decreased the after-flame and afterglow time and the inches of char length. There were distinct differences in the resistance to burning as the number of launderings increased. Differences were also noted in durability to the commercial laundering.

During the burning test many of the flame-retardant finished fabrics gave off a very obnoxious odor and smoke which required venting and removing between tests. The most offensive smoke was given off by the three fabrics finished with THPC-urea-MM and the three fabrics finished with THPOH-NH_3. The smoke from these fabrics had an acrid odor. There was still some smoke after the APO-THPC fabrics were laundered 5 times. The smoke decreased after additional launderings

with the exception of the 50/50 cotton/polyester blend fabric which continually gave off a heavy black smoke.

Some observations relate to the measured fire resistance characteristics. The two cotton/polyester blend fabrics burned with a quicker, brighter, and more intense flame than the 100 percent cotton. There was also beading, melting, and tearing associated with the burning of the blended fabrics. Some afterflame on the APO-THPC finished fabrics may be described as having a creeping movement as a small flame progressed along partially charred edges.

The char length for the THPOH-NH_3 finished fabrics was extremely fragile. For some measurements it resembled an ash network that disintegrated when the test frame and specimen were removed from the test cabinet. It could not be measured and was recorded as 0.0 inches.

FINDINGS RELATED TO FIRE RESISTANCE CHARACTERISTICS

Fire Resistance Characteristics Before Commercial Laundering

Afterflame. The afterflame time means were not significantly different among the three fabrics before commercial laundering. The afterflame time means were significantly different at the .01 level over all finishes. There was a mean afterflame time of 8.5 seconds for the unfinished fabrics and a mean afterflame time of 0.0 seconds for each of the three flame-retardant finished fabrics (Table 3).

Table 3

Mean Fire Resistance Characteristics and Level of Statistical Significance of Differences Before Commercial Laundering

	Fire Resistance Characteristics		
	Afterflame (seconds)	Afterglow (seconds)	Char Length (inches)
Fabrics			
100% cotton	2.2	4.6	3.8
70/30 blend	1.9	2.3	5.1
50/50 blend	2.3	0.1	5.6
Level of Statistical Significance	NS	**	**
Finishes			
Unfinished	8.5	9.5	0.0
APO-THPC	0.0	0.0	5.8
THPC-urea-MM	0.0	0.0	5.8
THPOH-NH_3	0.0	0.0	7.8
Level of Statistical Significance	**	**	**

Key for Level of Statistical Significance of Differences based on Analysis of Variance, F test
NS - Not significant
* - Significant at .05 level
** - Significant at .01 level

Afterglow. Highly significant differences in afterglow time means were recorded at the .01 level over all fabrics and over all finishes. The mean afterglow time decreased as the amount of cotton in the fabric blend decreased from 4.6 seconds for 100 percent cotton, to 2.3 seconds for the 70/30 cotton/polyester blend, to 0.1 second for the 50/50 cotton/polyester blend. The flame-retardant finishes were effective in preventing afterglow. For the unfinished fabrics there was a mean afterglow time of 9.5 seconds while there was no afterglow time for any of the three flame-retardant finished fabrics.

Char length. Highly significant differences in mean char length were recorded at the .01 level over all fabrics and over all finishes. The mean char length of 100 percent cotton fabric was 3.8 inches while the char lengths of the blended fabrics were 5.1 inches for the 70/30 cotton/polyester and 5.6 inches for the 50/50 cotton/polyester. When unfinished the fabrics burned the entire length and the result is shown by a mean of 0.0 inches. The mean char length of fabrics finished by APO-THPC and THPC-urea-MM were the same, 5.8 inches, while the mean char length of the THPOH-NH_3 finished fabrics was 7.8 inches. The flame-retardant finishes prevented the specimens burning the entire length.

Over All Fire Resistance Characteristics After Commercial Laundering

The changes in afterflame, afterglow, and char length have been analyzed statistically and the means tabulated. The mean of the unlaundered or 0 lqunderings fabrics has been included for purposes

of comparison in some of the tables and figures describing each fire resistance characteristic (Table 4 and Figure 2).

Afterflame. The mean afterflame times indicated highly significant differences at the .01 level for the fabrics, finishes, laundries, and launderings. There was no significant difference between the dry-fold and ironing treatments.

The mean afterflame time increased as the amount of cotton decreased in the fabric blends from 4.4 seconds for 100 percent cotton to 7.9 seconds for 50/50 cotton/polyester blend.

The THPC-urea-MM exhibited the least mean afterflame time, 3.1 seconds, among the three flame-retardant finishes. The mean time for APO-THPC was 6.5 seconds and for THPOH-NH_3 was 6.6 seconds.

The mean afterflame time of 5.9 seconds for Laundry A was significantly less than the mean afterflame time of 6.9 seconds for Laundry B. As the number of launderings increased, the mean afterflame time increased significantly from 3.8 seconds to 6.6 seconds to 8.7 seconds for 5, 10, and 20 launderings respectively.

Afterglow. There was a highly significant difference at the .01 level for the mean afterglow times of the fabrics, finishes, and launderings. The difference was significant at the .05 level between the means of the two laundries. No significant differences were found between the means of the dry-fold and ironing treatments.

The mean afterglow times for fabrics ranged from 4.7 to 1.2 to 0.2 seconds for the 100 percent cotton, 70/30 cotton/polyester blend, and 50/50 cotton/polyester blend respectively.

Table 4

Mean Fire Resistance Characteristics and Level of Statistical Significance of Differences After Commercial Laundering

	Fire Resistance Characteristics		
	Afterflame (seconds)	Afterglow (seconds)	Char Length (inches)
Fabrics			
100% cotton	4.4	4.7	5.0
70/30 blend	6.8	1.2	6.0
50/50 blend	7.9	0.2	6.4
Level of Statistical Significance	**	**	**
Finishes			
Unfinished	9.4	6.0	0.0
APO-THPC	6.5	0.0	9.1
THPC-urea-MM	3.1	0.0	7.4
THPOH-NH_3	6.6	2.0	6.7
Level of Statistical Significance	**	**	**
Treatments			
Dry-fold	6.2	2.0	5.8
Ironing	6.6	2.0	5.8
Level of Statistical Significance	NS	NS	NS
Commercial laundries			
Laundry A	5.9	1.7	6.3
Laundry B	6.9	2.3	5.3
Level of Statistical Significance	**	*	**
Launderings			
0	2.1	2.4	4.8
5	3.8	1.3	6.0
10	6.6	2.2	5.5
20	8.7	2.4	5.9
Level of Statistical Significance	**	**	**

Key for Level of Statistical Significance of Differences based on Analysis of Variance, F test
NS - Not significant
* - Significant at .05 level
** - Significant at .01 level

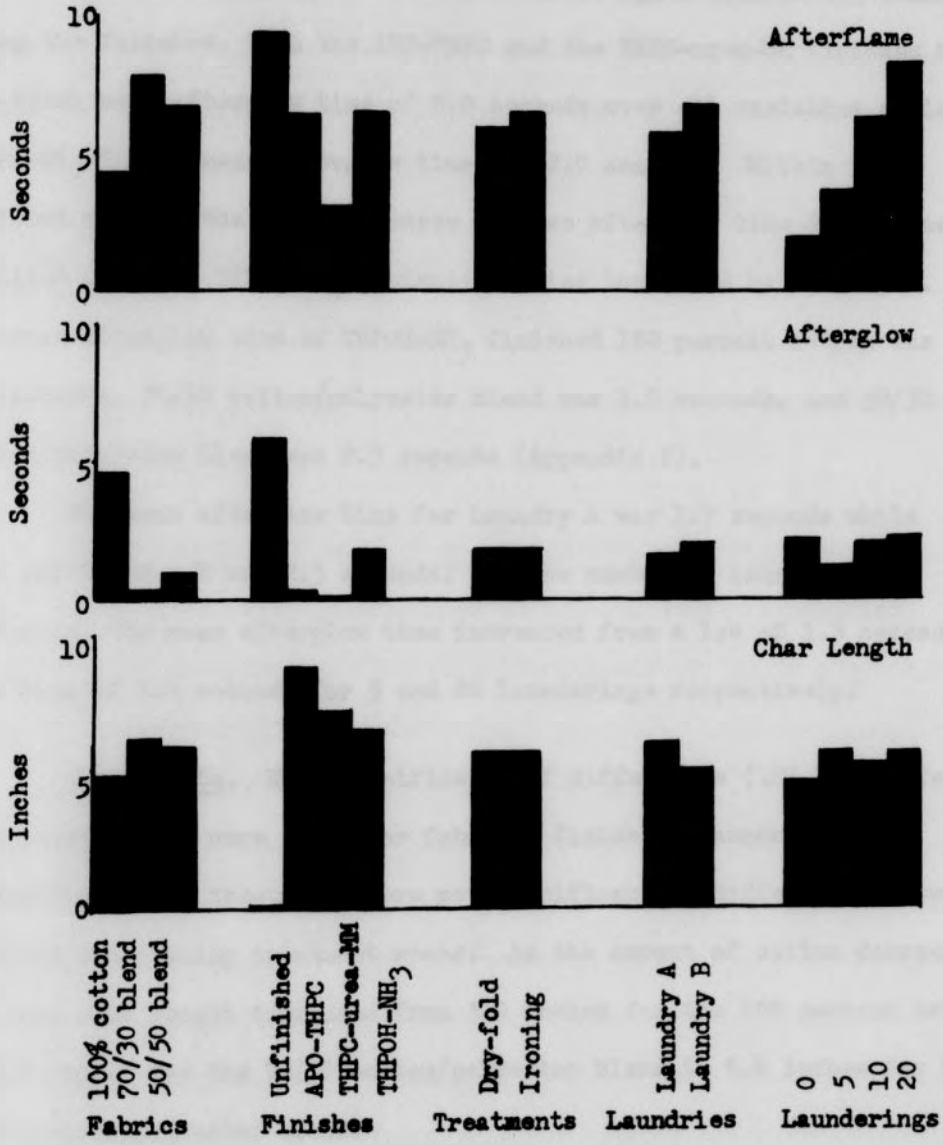

Figure 2

Fire Resistance Characteristics Over All Fabrics, Finishes, Treatments, Laundries, and Launderings

The unfinished fabrics had a mean afterglow time of 6.0 seconds. Among the finishes, both the APO-THPC and the THPC-urea-MM finishes had the ideal mean afterglow time of 0.0 seconds over all variables while the THPOH-NH_3 finish mean afterglow time was 2.0 seconds. Within the finished fabrics the primary source of mean afterglow time difference resulted from the THPOH-NH_3 finished fabrics laundered by Laundry B. The mean afterglow time of THPOH-NH_3 finished 100 percent cotton was 8.5 seconds, 70/30 cotton/polyester blend was 3.0 seconds, and 50/50 cotton/polyester blend was 0.3 seconds (Appendix B).

The mean afterglow time for Laundry A was 1.7 seconds while that for Laundry B was 2.3 seconds. As the number of launderings increased, the mean afterglow time increased from a low of 1.3 seconds to a high of 2.4 seconds for 5 and 20 launderings respectively.

Char length. High significance of differences (.01 level) for char length means were found for fabrics, finishes, laundries, and launderings. The treatments were not significant in differences between dry-fold and ironing treatment means. As the amount of cotton decreased, the mean char length increased from 5.0 inches for the 100 percent cotton to 6.0 inches for the 70/30 cotton/polyester blend to 6.4 inches for the 50/50 cotton/polyester blend.

When the fabrics were unfinished, there was no char length since they burned the entire length. The mean char length was 7.4 inches for THPC-urea-MM finished fabrics and 9.1 inches for APO-THPC. The mean char length of the THPOH-NH_3 finish was 6.7 inches which included some char length measurements of 0.0 inches when the fabrics burned the entire length.

The mean char length was 6.3 inches when specimens were laundered by Laundry A and 5.3 inches when laundered by Laundry B. The mean char length was slightly less after 10 launderings (5.5 inches) than it was for 5 and 20 launderings (6.0 inches and 5.9 inches) respectively.

Fire Resistance Characteristics of Unfinished Fabrics After Commercial Laundering

Further analyses of variance were computed to determine significances of differences for the unfinished fabrics separately from the flame-retardant finished fabrics (Table 5).

Afterflame. The means of the laundered unfinished fabrics showed highly significant differences at the .01 level for fabrics, laundries, and launderings. The afterflame means of the treatments were not significantly different.

Comparison of fabric means indicates that the 100 percent cotton had the lowest mean afterflame time, 8.4 seconds, followed by 50/50 cotton/polyester blend, 8.9 seconds. Graphic comparison indicated that the 50/50 cotton/polyester blend as laundered by Laundry A with dry-fold treatment had excessively high afterflame variation as the number of launderings increased. The fabric fluctuated in mean afterflame time from 8.5 seconds after 5 launderings to 6.7 seconds after 10 launderings, to 15.5 seconds after 20 launderings (Table 6 and Figure 3). The 70/30 cotton/polyester blend had the greatest mean afterflame time, 10.8 seconds.

Laundry A had a greater mean afterflame time, of 10.0 seconds, than Laundry B with 8.8 seconds.

Table 5

Mean Fire Resistance Characteristics and Level of Statistical Significance of Differences for Unfinished Fabrics After Laundering

	Fire Resistance Characteristics		
	Afterflame (seconds)	Afterglow (seconds)	Char Length (inches)
Fabrics			
100% cotton	8.4	14.5	0.0
70/30 blend	10.8	3.1	0.0
50/50 blend	8.9	0.4	0.0
Level of Statistical Significance	**	*	NS
Treatments			
Dry-fold	9.2	6.1	0.0
Ironing	9.6	5.9	0.0
Level of Statistical Significance	NS	NS	NS
Commercial Laundries			
Laundry A	10.0	6.7	0.0
Laundry B	8.8	5.3	0.0
Level of Statistical Significance	**	NS	NS
Launderings			
5	9.4	5.4	0.0
10	8.4	6.3	0.0
20	10.4	6.3	0.0
Level of Statistical Significance	**	NS	NS

Key for Level of Statistical Significance of Differences based on Analysis of Variance, F test
NS - Not significant
* - Significant at .05 level
** - Significant at .01 level

Table 6

Mean Afterflame Time in Seconds of Unfinished Fabrics After Commercial Laundering

Fabric	Unlaundered	Dry-fold Treatment						Ironing Treatment					
		Laundry A			Laundry B			Laundry A			Laundry B		
		5	10	20	5	10	20	5	10	20	5	10	20
100% cotton	8.7	10.1	7.7	10.4	6.7	5.9	7.3	8.5	7.0	10.3	9.4	8.1	9.4
70/30 blend	7.7	12.2	10.5	10.6	10.7	9.9	11.3	11.1	11.1	10.5	10.5	10.0	11.9
50/50 blend	9.3	8.5	6.7	15.5	6.9	7.8	6.7	9.0	9.0	11.7	8.8	7.4	9.2

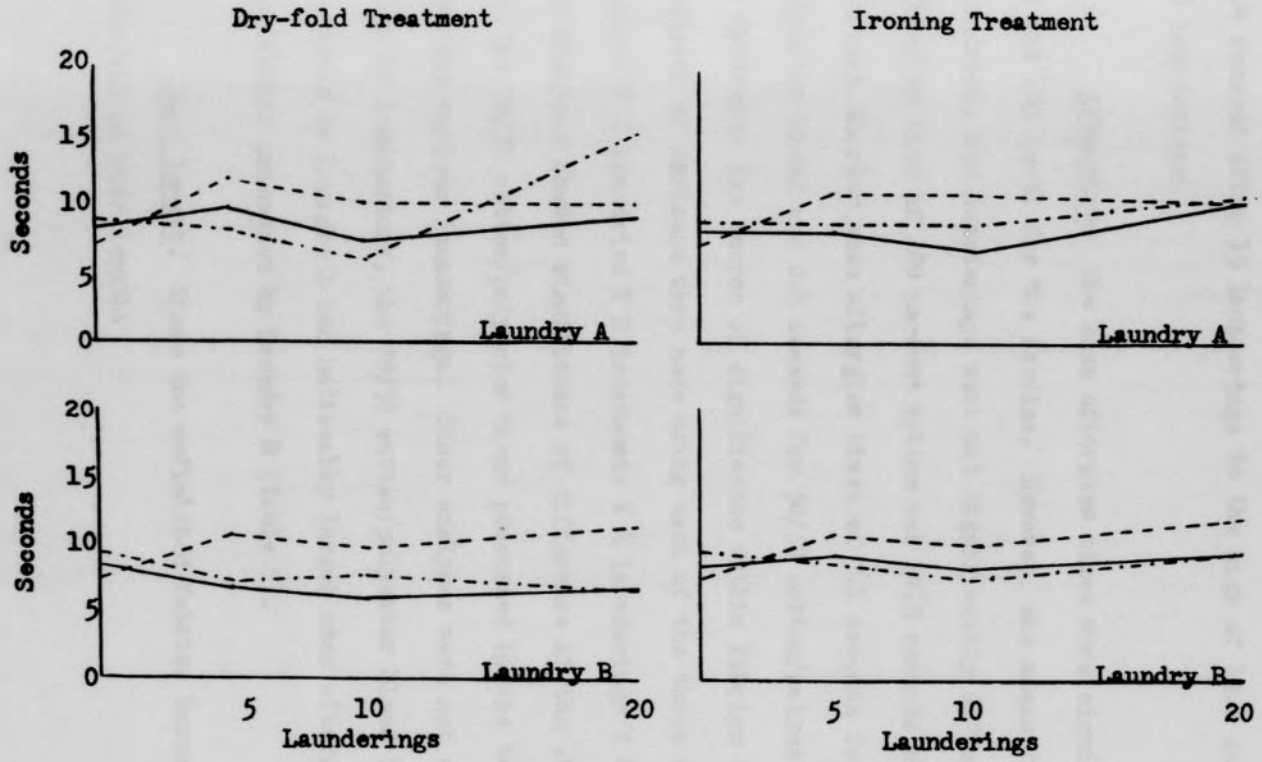

Figure 3

Mean Afterflame Time in Seconds of Unfinished Fabrics Following Laundering by Two Laundries Using Two Treatments

Key
—— 100% cotton
- - 70/30 blend
-·-· 50/50 blend

The mean afterflame time of the launderings was also high with a difference of only two seconds between the low afterflame of 8.4 seconds after 10 launderings to the high of 10.4 seconds after 20 launderings.

Afterglow. The mean afterglow times were significantly different at the .05 level for the fabrics. However, the means for the treatments, laundries, and launderings were not significantly different. The mean afterglow time of 100 percent cotton was 14.5 seconds while the blends had much shorter mean afterglow times of 3.1 seconds for 70/30 cotton/polyester blend and 0.4 seconds for 50/50 cotton/polyester blend. To determine the source of significance within fabrics three additional analyses of variance were made using each of the three unfinished fabrics X 2 laundries X 2 treatments X 3 launderings X 4 replications. The analyses showed significance of difference at the .01 level only for the 70/30 cotton/polyester blend processed by the two laundries over the various launderings. Other analyses were not significant. After 20 launderings, the 70/30 cotton/polyester blend fabrics processed by Laundry A had noticeably larger mean afterglow times than the fabrics processed by Laundry B (Table 7).

Char length. Since the unfinished fabrics burned completely, there was no char length.

Table 7

Mean Afterglow Time in Seconds of Unfinished Fabrics After Commercial Laundering

Fabric	Unlaundered	Dry-fold Treatment						Ironing Treatment					
		Laundry A			Laundry B			Laundry A			Laundry B		
		5	10	20	5	10	20	5	10	20	5	10	20
100% cotton	18.6	15.5	18.8	13.3	18.3	10.6	10.3	13.9	22.4	7.9	9.3	1[illegible].9	17.9
70/30 blend	9.3	1.2	2.0	11.4	1.2	0.8	3.4	1.9	3.3	7.4	2.1	1.2	2.0
50/50 blend	0.6	0.0	0.2	0.8	0.0	0.5	1.1	0.0	0.0	0.6	1.2	0.2	0.0

Table 7

Mean Afterglow Time in Seconds of Unfinished Fabrics After Commercial Laundering

Fabric	Unlaundered	Dry-fold Treatment						Ironing Treatment					
		Laundry A			Laundry B			Laundry A			Laundry B		
		5	10	20	5	10	20	5	10	20	5	10	20
100% cotton	18.6	15.5	18.8	13.3	18.3	10.6	10.3	13.9	22.4	7.9	9.3	15.9	17.9
70/30 blend	9.3	1.2	2.0	11.4	1.2	0.8	3.4	1.9	3.3	7.4	2.1	1.2	2.0
50/50 blend	0.6	0.0	0.2	0.8	0.0	0.5	1.1	0.0	0.0	0.6	1.2	0.2	0.0

Fire Resistance Characteristics of Flame-Retardant Finished Fabrics After Commercial Laundering

Afterflame. The mean afterflame times of the flame-retardant finished fabrics were significantly different at the .01 level for fabrics, finishes, laundries, and launderings. The mean afterflame time was not significantly different for treatments.

Among the fabrics finished with APO-THPC laundered by Laundry A with the dry-fold treatment, the 50/50 cotton/polyester blend showed high and varied mean afterflame times. The mean afterflame time was 11.7 seconds after 5 launderings, 19.1 seconds after 10 launderings, and 10.6 seconds after 20 launderings. It was noted in the visual observation of the burning characteristic that a small creeping flame progressed around the charred and uncharred edge. When laundered by Laundry B with the dry-fold treatment, the three fabrics were more consistent in mean afterflame pattern (Table 8 and Figure 4).

The APO-THPC finished fabrics laundered by Laundry A with the ironing treatment resulted in the 100 percent cotton having a low mean afterflame time of 1.5 seconds after 20 launderings, while the 70/30 cotton/polyester blend and 50/50 cotton/polyester blend had high mean afterflame times of 14.1 and 15.0 seconds respectively. The 100 percent cotton processed by Laundry B had a mean afterflame time which increased from 0.0 seconds for 5 launderings to 6.1 seconds for 20 launderings. The 70/30 cotton/polyester blend indicated more variation as the mean afterflame time was 0.9 seconds for 5 launderings, 12.4 seconds for 10 launderings, and 11.0 seconds for 20 launderings.

Table 8

Mean Afterflame Time in Seconds of Flame-Retardant Finished Fabrics After Commercial Laundering

Finish and Fabric	Unlaundered	Dry-fold Treatment						Ironing Treatment					
		Laundry A			Laundry B			Laundry A			Laundry B		
		5	10	20	5	10	20	5	10	20	5	10	20
APO-THPC													
100% cotton	0.0	0.0	0.0	5.8	0.0	5.3	9.4	0.0	0.0	1.5	0.0	5.6	6.1
70/30 blend	0.0	0.0	0.0	10.2	0.0	7.8	15.1	0.0	6.0	14.1	0.9	12.4	11.0
50/50 blend	0.0	11.7	19.1	10.6	0.0	8.2	9.5	2.4	11.3	15.0	8.5	11.6	14.2
THPC-urea-MM													
100% cotton	0.0	0.0	0.0	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0	0.0	5.1
70/30 blend	0.0	0.0	0.0	0.0	0.0	11.1	8.6	0.0	0.0	0.0	0.0	10.0	9.9
50/50 blend	0.0	0.0	0.0	2.5	0.0	6.4	7.6	0.0	0.0	18.3	0.0	12.8	10.2
THPOH-NH_3													
100% cotton	0.0	2.8	5.3	8.9	1.3	7.6	6.5	3.4	5.6	7.6	3.3	5.3	6.6
70/30 blend	0.0	1.7	7.3	6.7	3.1	11.8	14.0	0.5	2.0	9.1	2.0	13.5	9.3
50/50 blend	0.0	7.6	12.3	10.5	6.4	5.2	6.8	7.6	6.2	9.1	9.0	6.5	7.2

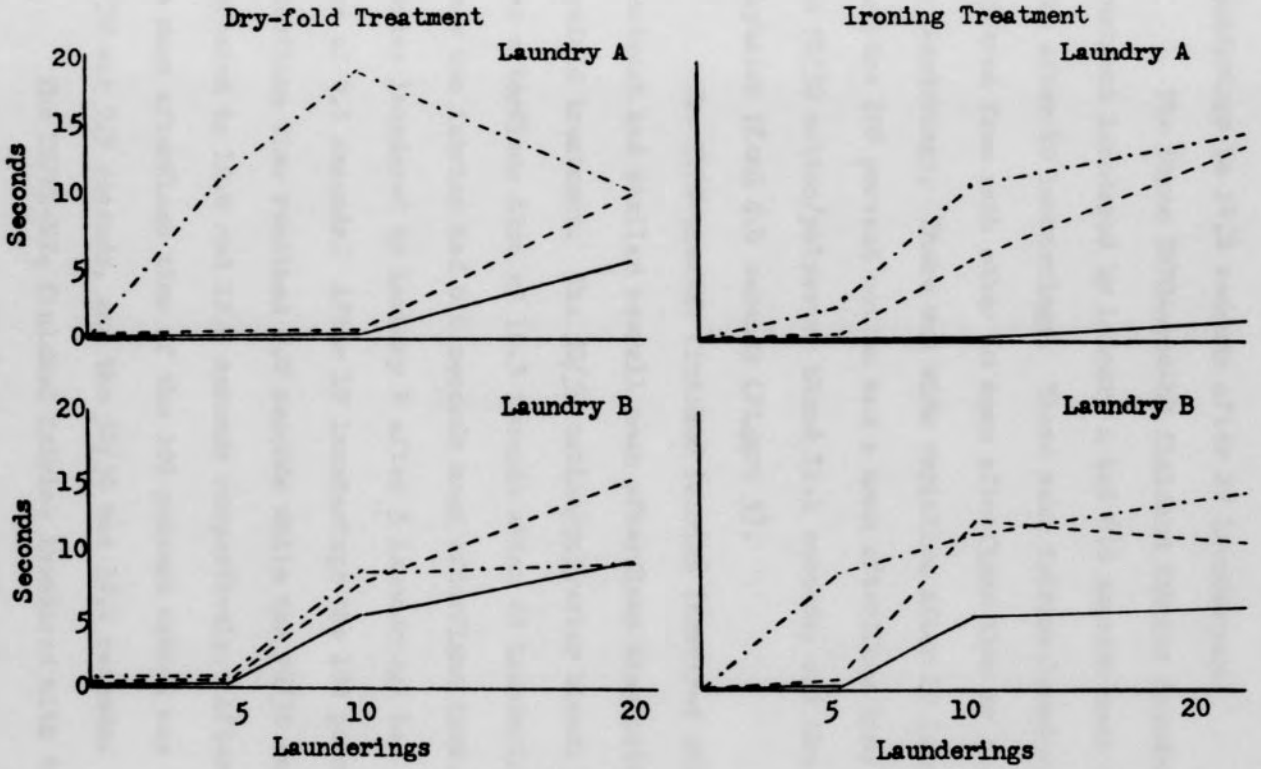

Figure 4

Mean Afterflame Time in Seconds of APO-THPC Finished Fabrics Following Laundering by Two Laundries Using Two Treatments

Key
—— 100% cotton
-- 70/30 blend
--- 50/50 blend

The 50/50 cotton/polyester blend laundered by Laundry B with the ironing treatment had mean afterflame times ranging from 8.6 seconds after 5 launderings to 14.2 seconds after 20 launderings.

The three THPC-urea-MM finished fabrics laundered with dry-fold treatment laundered by Laundry A had 0.0 seconds mean afterflame time even after 20 launderings. These same fabrics laundered by Laundry B differed from each other in mean afterflame time by 1 second after 20 launderings. There was wide variation after 10 launderings though, when, the 100 percent cotton had a mean afterflame time of 0.0 seconds, the 70/30 cotton/polyester blend 11.1 seconds, and the 50/50 cotton/polyester blend 6.4 seconds (Figure 5).

The THPC-urea-MM finished fabrics laundered with ironing treatment had similar overall mean afterflame time patterns as with the dry-fold treatment. The 50/50 cotton/polyester blend, however, had a mean afterflame time of 18.3 seconds after 20 launderings while the other two fabrics had 0.0 seconds mean afterflame time. The three fabrics laundered by Laundry B after 5 launderings had a mean afterflame time of 0.0 seconds. After 10 launderings the 100 percent cotton mean afterflame time remained 0.0 seconds while the 70/30 and 50/50 blends increased to 10.0 and 12.8 seconds respectively. After 20 launderings the mean afterflame time of the 100 percent cotton was 5.1 seconds, the 70/30 was 9.9 seconds, and the 50/50 was 10.2 seconds.

The THPOH-NH_3 finished fabrics laundered with the dry-fold treatment by Laundry A resulted in two different mean afterflame time patterns. The 100 percent cotton had an increasing mean afterflame

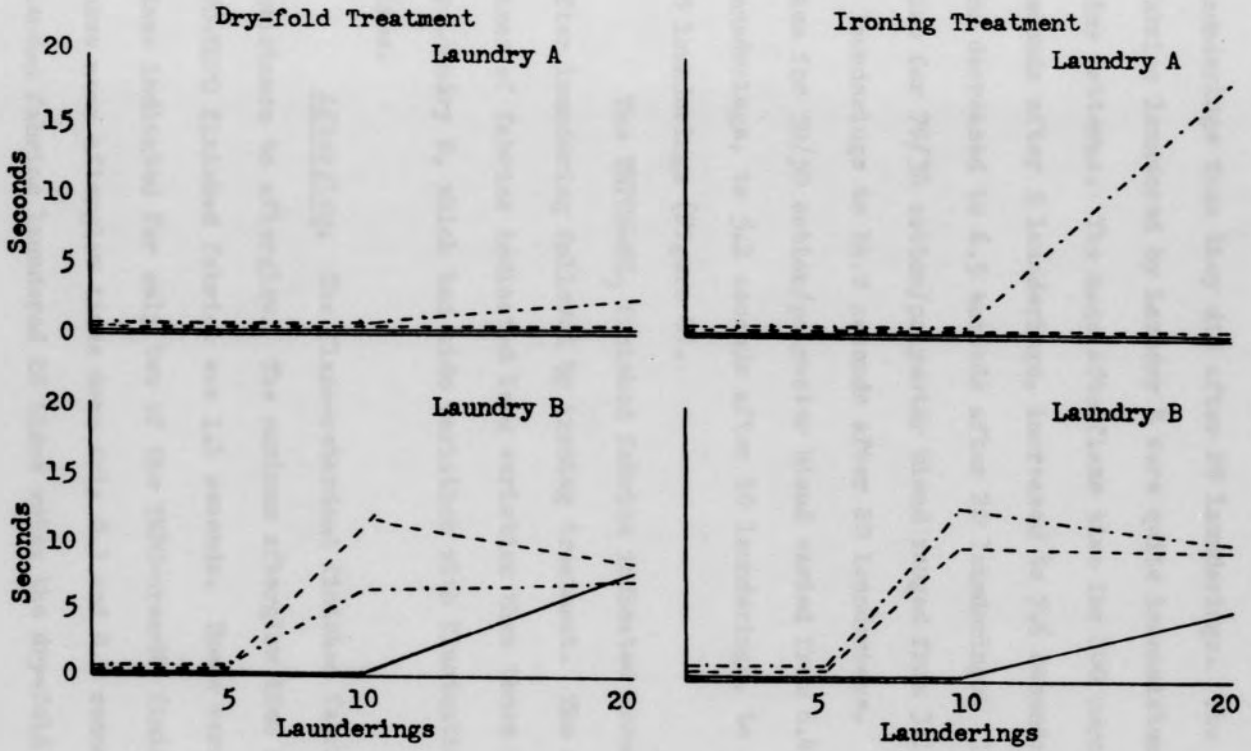

Figure 5

Mean Afterflame Time in Seconds of THPC-urea-MM Finished Fabrics Following Laundering by Two Laundries Using Two Treatments

Key
—— 100% cotton
- - - 70/30 blend
-·-· 50/50 blend

time pattern with additional launderings while the 70/30 and the 50/50 cotton/polyester blends had higher mean afterflame times following 10 launderings than they did after 20 launderings. The dry-fold treatment fabrics laundered by Laundry B were quite inconsistent in mean afterflame time patterns. The mean afterflame time for 100 percent cotton was 1.3 seconds after 5 launderings, increased to 7.6 seconds after 10 launderings, and decreased to 6.5 seconds after 20 launderings. The mean afterflame time for 70/30 cotton/polyester blend ranged from 3.1 seconds after 5 launderings to 14.0 seconds after 20 launderings. The mean afterflame time for 50/50 cotton/polyester blend varied from 6.4 seconds after 5 launderings, to 5.2 seconds after 10 launderings, to 6.8 seconds after 20 launderings (Figure 6).

The THPOH-NH_3 finished fabrics indicated inconsistent differences after laundering followed by ironing treatment. The mean afterflame times of fabrics indicated less variation than those fabrics laundered by Laundry B, which had wide variation with fluctuating mean afterflame times.

Afterglow. The flame-retardant finished fabrics had excellent resistance to afterglow. The maximum afterglow time for any of the APO-THPC finished fabrics was 1.1 seconds. There were mean afterglow times indicated for only two of the THPC-urea-MM finished fabrics. These mean afterglow times were only 0.3 and 0.1 seconds for the two blended fabrics laundered 20 times using the dry-fold treatment by Laundry B.

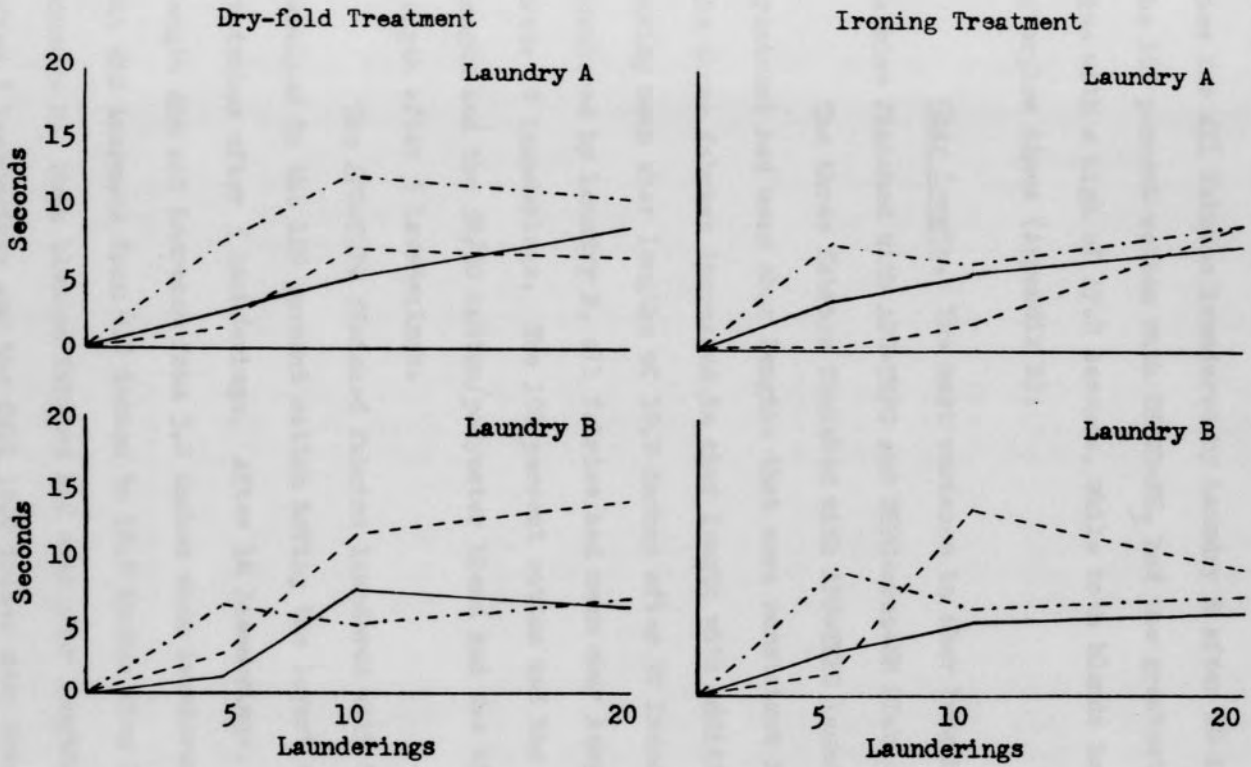

Figure 6

Mean Afterflame Time in Seconds of THPOH-NH_3 Finished Fabrics Following Laundering by Two Laundries Using Two Treatments

Key
—— 100% cotton
- - - 70/30 blend
- · - · 50/50 blend

There was no mean afterglow time for the THPOH-NH_3 finished fabrics laundered by Laundry A. There was, however, mean afterglow time for all fabrics laundered by Laundry B after 10 launderings. The 100 percent cotton with THPOH-NH_3 had the greatest mean afterglow time with a high of 17.2 seconds, while both blends had much lower mean afterglow times (Appendix B).

Char length. The most variance in char length occurred in the fabrics finished with APO-THPC and THPC-urea-MM (Table 9).

The three fabrics finished with APO-THPC laundered with dry-fold treatment had mean char lengths that were consistent for both laundries. The three fabrics increased in char length with additional launderings, having mean char lengths of 10.0 inches after 20 launderings. When laundered by Laundry B, all fabrics had mean char lengths of 10.0 inches after 10 launderings. The 100 percent cotton had the lowest mean char length and the 50/50 cotton/polyester blend had the highest mean char length after 5 launderings.

The APO-THPC finished fabrics laundered with ironing treatment resulted in the 100 percent cotton having the lowest mean char length in inches after 5 launderings. After 10 launderings, the mean char length did not increase from 5.2 inches when laundered by Laundry A, but did increase from 4.8 inches to 10.0 inches when laundered by Laundry B. Both blended fabrics had mean char lengths above 9.0 inches after 5 launderings and the full 10.0 inches mean char length after 10 launderings (Figure 7).

Table 9

Mean Char Length in Inches of Flame-Retardant Finished Fabrics Before and After Laundering

Finish and Fabric	Unlaundered	Dry-fold Treatment						Ironing Treatment					
		Laundry A			Laundry B			Laundry A			Laundry B		
		5	10	20	5	10	20	5	10	20	5	10	20
APO-THPC													
100% cotton	4.4	4.9	8.0	10.0	4.3	10.0	10.0	5.2	5.2	10.0	4.8	10.0	10.0
70/30 blend	6.3	8.9	9.6	10.0	8.0	10.0	10.0	9.4	10.0	10.0	9.9	10.0	10.0
50/50 blend	6.6	10.0	10.0	10.0	10.0	10.0	10.0	9.8	10.0	10.0	10.0	10.0	10.0
THPC-urea-MM													
100% cotton	5.0	4.5	3.8	4.8	4.3	9.0	10.0	4.1	4.1	4.3	4.1	7.1	10.0
70/30 blend	6.6	5.5	5.6	6.9	6.6	10.0	10.0	6.6	6.2	7.4	6.5	10.0	10.0
50/50 blend	5.7	7.1	7.2	9.9	8.5	10.0	10.0	6.9	8.3	10.0	7.7	10.0	10.0
THPOH-NH_3													
100% cotton	5.9	10.0	10.0	10.0	10.0	0.0	0.0	10.0	10.0	10.0	10.0	0.0	0.0
70/30 blend	7.6	10.0	10.0	10.0	10.0	0.0	0.0	10.0	10.0	10.0	10.0	0.0	0.0
50/50 blend	9.5	10.0	10.0	10.0	10.0	0.0	0.0	10.0	10.0	10.0	10.0	0.0	0.0

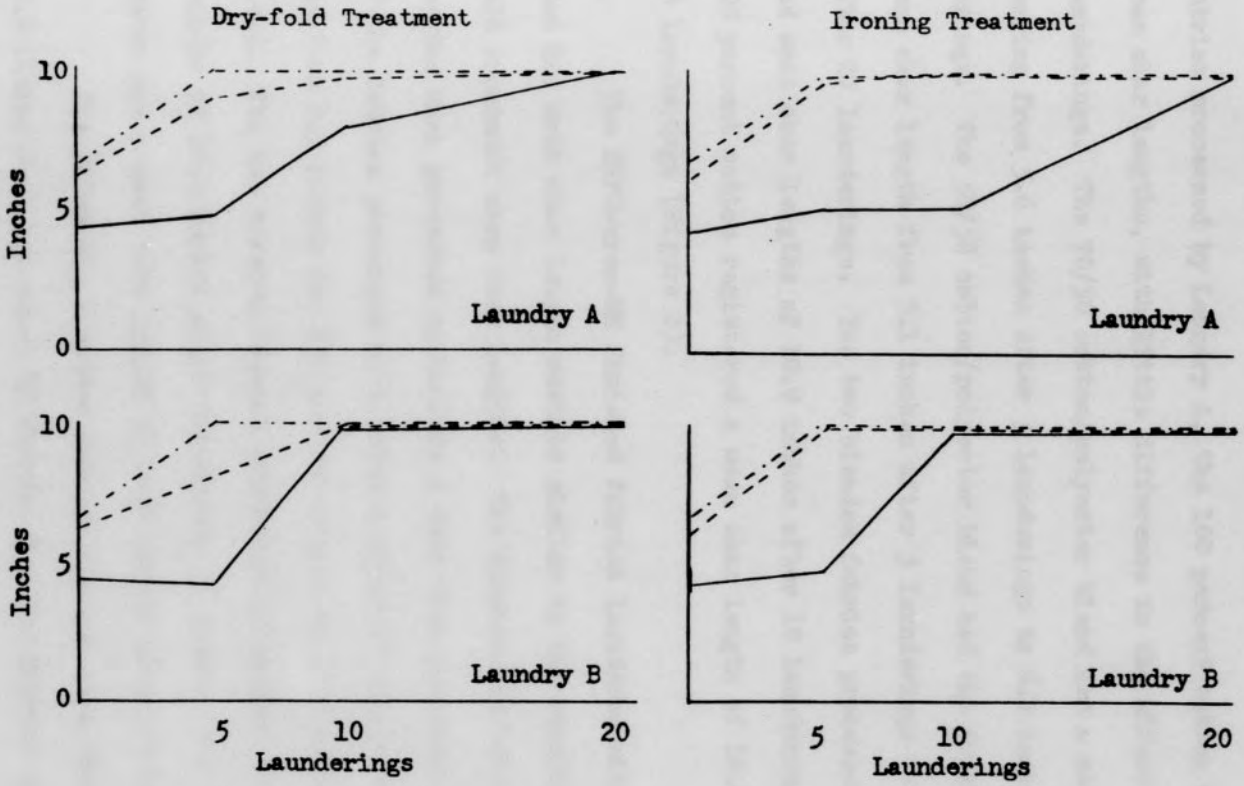

Figure 7

Mean Char Length in Inches of APO-THPC Finished Fabrics Following Laundering by Two Laundries Using Two Treatments

Key
——100% cotton
- - -70/30 blend
·-·-·50/50 blend

The fabrics finished with THPC-urea-MM gave consistent results for each laundry, but not for each treatment. For the dry-fold treatment fabrics processed by Laundry A, the 100 percent cotton had the lowest mean char lengths, with little difference in the effect of multiple launderings. The 70/30 cotton/polyester blend had a mean char length ranging from 5.6 inches after 5 launderings to 6.9 inches after 20 launderings. The 50/50 cotton/polyester blend had the greatest increase in mean char length from 7.1 inches after 5 launderings to 10.0 inches after 20 launderings. The two blended fabrics processed by Laundry B had mean char lengths of 10.0 inches after 10 launderings, whereas the 100 percent cotton registered a mean char length of 10.0 inches after 20 launderings (Figure 8).

The THPC-urea-MM finished fabrics laundered with ironing treatment had mean char length results similar to the results for the dry-fold treatment mean char lengths. The fabrics had lower mean char lengths when processed by Laundry A than when processed by Laundry B. Of the fabrics processed by Laundry A after 20 launderings, the range was from 4.3 inches for 100 percent cotton to 10.0 inches for the 50/50 blend. The two blended fabrics processed by Laundry B had mean char lengths of 10.0 inches after laundering 10 times. The 100 percent cotton had a mean char length of 10.0 inches after 20 launderings.

The THPOH-NH_3 finished fabrics all had mean char lengths of 10.0 inches when laundered by Laundry A. The fabrics laundered by Laundry B after 10 launderings burned the entire length and no char length remained.

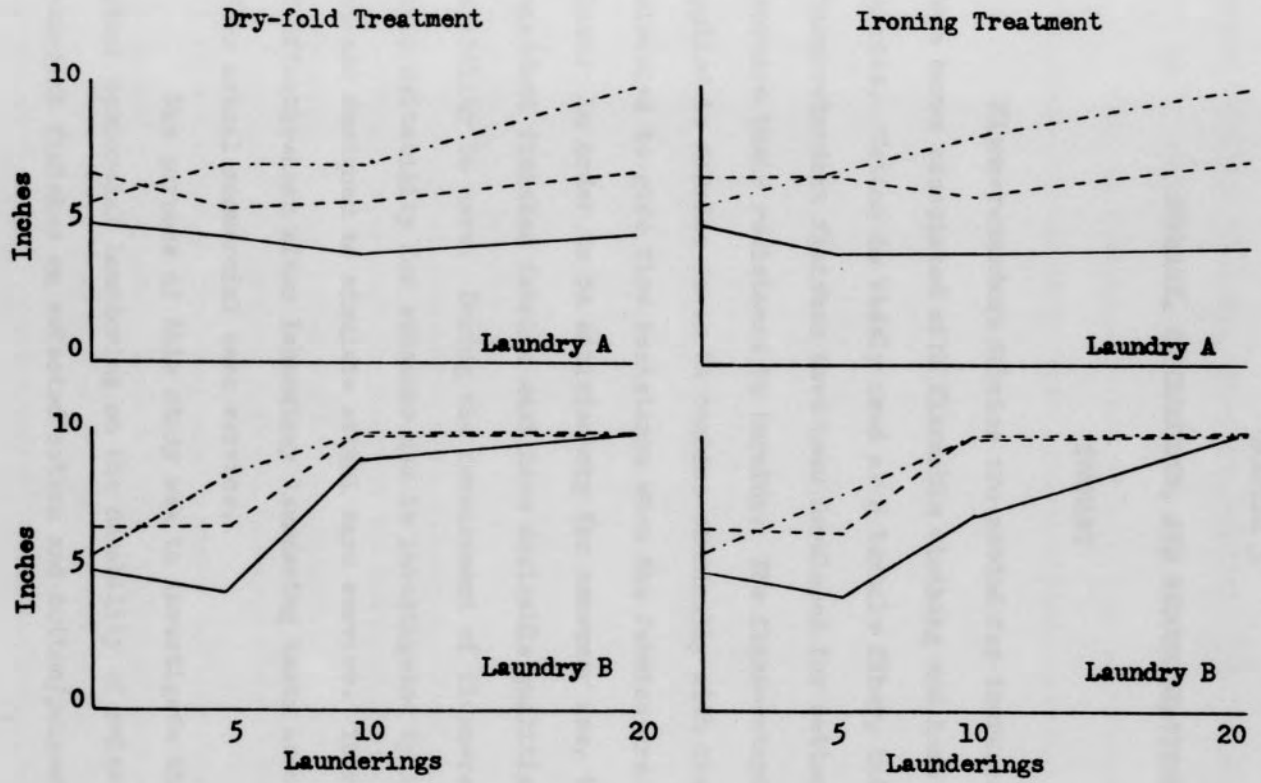

Figure 8

Mean Char Length in Inches of THPC-urea-MM Finished Fabrics Following Laundering by Two Laundries Using Two Treatments

Key
—— 100% cotton
- - - 70/30 blend
-·-· 50/50 blend

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

Flame-retardant fabrics are needed for increased protection from burns associated with flammable clothing and home furnishings fabrics. Cotton is widely used as a textile fiber, but it is flammable. Flame-retardant finishes have been developed for cotton fabrics to increase their resistance to burning. The flame-retardant finishes are applied to fabrics so as to combine chemically with the cellulose molecules to give fire resistance when the fabrics are exposed to flame. In order to be satisfactory for consumer use, the flame-retardant finished fabrics must have desirable qualities including durability to care. During the development of flame-retardant finishes their suitability for consumer use is investigated by laboratory test methods designed to simulate actual care service. There is a question of effectiveness after laboratory laundering tests as compared to testing after actual commercial care service.

The purpose of this study was to investigate the effects of actual commercial laundering on the durability of selected flame-retardant finishes on selected cotton and cotton/polyester blend fabrics.

The specific objectives of the study were:

1. To determine differences after laundering in fire resistance characteristics of three selected fabrics: (a) 100 percent cotton, (b) 70/30 cotton/polyester blend, and (c) 50/50 cotton/polyester blend.

2. To determine differences in fire resistance characteristics of fabrics treated with three selected flame-retardant finishes: (a) APO-THPC, (b) THPC-urea-MM, and (c) THPOH-NH_3.

3. To determine differences in fire resistance characteristics of selected finishes and fabrics as affected by dry-fold and ironing laundering treatments. The two treatments were used as a means of indicating the effect of heat upon the durability of the finishes.

4. To determine differences in fire resistance characteristics of the selected fabrics and fire-retardant finishes before laundering and after 5, 10, and 20 launderings.

Description of Fabrics Used

A study of flame-retardant fabrics has been undertaken by the Agricultural Experiment Stations of the Southern Region under the sponsorship of the United States Department of Agriculture. This study was designated as Southern Regional Research Project SM-38. The fabrics and flame-retardant finishes were prepared for experimental purposes by the Southern Utilization Research and Development Division.

The fiber contents of the three experimental fabrics were 100 percent cotton, 70/30 cotton/polyester blend, and 50/50 cotton/polyester blend. Samples of each of the three fabric types were prepared with each

of the three selected flame-retardant finishes; tris-(1-aziridinyl) phosphine oxide tetrakis (hydroxymethyl) phosphonium chloride (APO-THPC), tetrakis (hydroxymethyl) phosphonium chloride urea methylolmelamine (THPC-urea-MM), and tetrakis (hydroxymethyl) phosphonium hydroxide ammonia cure (THPOH-NH_3). One group of each of the three fabric types had no flame-retardant finish applied and was designated as unfinished.

Test sheets of unfinished and flame-retardant finished fabrics were prepared in the laboratory for laundering by two laundries.

Description of Laundering

The test sheets were designated to receive white wash laundering followed by either dry-fold or ironing treatment. Fabric specimens were withdrawn after 5, 10, or 20 launderings. One set was not laundered for purposes of comparison.

Description of Fire Resistance Testing

After laundering, the test specimens were observed for subjective evidence of durability of the flame-retardant finishes. The specimens were then tested for fire resistance by the AATCC Vertical Test Method 34-1966. The results were reported as afterflame in seconds, afterglow in seconds, and char length in inches.

Significances of difference were determined from the data by analyses of variance. Separate analyses of variance were made of the unlaundered control fabrics and finishes, laundered fabrics and finishes, laundered unfinished fabrics, and laundered finished fabrics. Findings were considered significant at the .05 level of significance and highly significant at the .01 level of significance.

Performance Observations

Application of the flame-retardant finishes changed the appearance of the three fabrics. The changes in appearance included changes in color and hand. After laundering there were some changes in color. Differences in color change were noted between laundries, between treatments, and between launderings. The application of the flame-retardant finish made the fabrics firmer in the hand of the fabrics. There were differences in hand noted between treatments and between launderings. There were no differences in hand noted between laundries.

The application of the flame-retardant finish made definite differences in the burning characteristics when the fabrics were exposed to flame. The flame-retardant finished fabrics had less afterflame, and less afterglow than the unfinished fabrics. The unfinished fabrics burned completely. For the flame-retardant finished fabrics there was generally a measurable char length remaining after exposure to flame. Many of the flame-retardant finished fabrics gave off objectionable smoke and odors as they burned.

Fire Resistance Characteristics
Before Commercial Laundering

Before laundering only the unfinished fabrics had any afterflame or afterglow. The flame-retardant finished fabrics indicated no afterflame or afterglow. The unfinished fabrics burned completely and no char length remained. The flame-retardant finishes prevented the fabrics from burning and had measurable char lengths. The analysis of variance indicated no significant difference in mean afterflame time

among the fabrics, but the difference was highly significant among all the finishes as a result of the afterflaming of the unfinished fabrics. The differences were highly significant for afterglow and char length for both fabrics and finishes.

Fire Resistance Characteristics
After Commercial Laundering

Afterflame. The mean afterflame times indicated highly significant differences at the .01 level for fabrics, finishes, laundries and launderings. There was no significant difference for the mean afterflame times between the dry-fold and ironing treatments. Significant differences resulted primarily between the unfinished and flame-retardant finished fabrics. Further analyses of variance were used to determine the source of significant differences.

Afterglow. The mean afterglow times resulted in highly significant differences at the .01 level for fabrics, finishes, and launderings. The mean afterglow times were significant at the .05 level between laundries. There were no significant differences between the mean afterflame times of the dry-fold and ironing treatments. Significant differences resulted primarily between the unfinished and flame-retardant finished fabrics. Further analyses of variance were used to determine the source of significant differences.

Char length. The mean char lengths indicated highly significant differences at the .01 level for fabrics, finishes, laundries, and launderings. There was no significant difference between the mean char lengths as a result of dry-fold or ironing treatment. The unfinished fabrics burned the entire length and no char length remained.

Fire Resistance Characteristics of Unfinished Fabrics After Commercial Laundering

Afterflame. Highly significant differences at the .01 level resulted between the mean afterflame times of fabrics, laundries, and launderings. The mean afterflame times were not significantly different between dry-fold and ironing treatments.

Afterglow. The mean afterglow times were significantly different at the .05 level for fabrics. The mean afterglow times were not significantly different for treatments, laundries, and launderings. Further analyses of variance by each fabric type indicated the source of variation was the 70/30 cotton/polyester blend processed by the two laundries over the various launderings.

Char length. There was no char length for the unfinished fabrics.

Fire Resistance Characteristics of Flame-Retardant Finished Fabrics After Commercial Laundering

Afterflame. Differences were highly significant at the .01 level for mean afterflame times of fabrics, finishes, laundries, and launderings. There was no significant difference in mean afterflame time between dry-fold and ironing treatments. There was no primary source of variation so each flame-retardant finish was analyzed and described separately by fabric, treatment, laundry, and launderings.

Afterglow. The flame-retardant finished fabrics had excellent resistance to afterglow. The least desirable afterglow was exhibited by the 100 percent cotton with THPOH-NH_3 laundered by Laundry B.

Char length. The primary variance in char length occurred in the fabrics finished with APO-THPC and THPC-urea-MM. The least desirable char length occurred in the THPOH-NH_3 finished fabrics laundered by Laundry B. These fabrics burned completely after 10 launderings.

CONCLUSIONS

The results of this study indicate the following conclusions:

1. The resistance to fire decreases as the amount of cotton in a fabric blend decreases.

2. The flame-retardant finishes are effective in decreasing the amount of afterflame and afterglow time and in increasing the amount of char length.

3. There were differences among flame-retardant finishes in the effectiveness after commercial laundering. The differences were related to other variables and there was no one most desirable finish.

4. There is a difference in the effectiveness of flame-retardant finishes after laundering by two laundries.

5. There is very little difference in the effect of dry-fold and ironing treatments on durability of finishes.

6. The effect of increased launderings is decreased fire resistance.

RECOMMENDATIONS

The difference in fire resistance characteristics was greater than anticipated between the two laundries. Further investigation would be desirable to develop a better understanding of the effect of various

laundering products on flame-retardant finished fabrics. The following recommendations are made for further study:

1. Determination of the effect of various detergents and soaps on the durability of flame-retardant finished fabrics.

2. Determination of the effect of bleaching agents on the durability of flame-retardant finished fabrics.

3. Determination of the effect of acid sours on the durability of flame-retardant finished fabrics.

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APPENDIX A

APPENDIX A

Mean Afterflame Time in Seconds of Unfinished and Flame-Retardant Finished Fabrics Before and After Laundering

Fabric and Finish	Unlaundered	Laundry A								Laundry B							
		Dry fold				Ironing treatment				Dry fold				Ironing treatment			
		5	10	20	Mean	5	10	20	Mean	5	10	20	Mean	5	10	20	Mean
Unfinished																	
100% cotton	8.7	10.1	7.7	10.4	9.4	8.5	7.0	10.3	8.6	6.7	5.9	7.3	6.6	9.4	8.1	9.4	9.0
70/30 blend	7.7	12.2	10.5	10.6	11.1	11.1	11.1	10.5	10.9	10.7	9.9	11.3	10.6	10.5	10.1	11.9	10.8
50/50 blend	9.3	8.5	6.7	15.5	10.2	9.0	9.0	11.7	9.9	6.9	7.8	6.7	7.1	8.8	7.4	9.2	8.4
Mean	8.5	10.3	8.3	12.1	10.2	9.5	9.0	10.8	9.8	8.1	7.8	8.4	8.1	9.6	8.5	10.1	9.4
APO-THPC																	
100% cotton	0.0	0.0	0.0	5.8	1.9	0.0	0.0	1.5	0.5	0.0	5.3	9.4	4.9	0.0	5.6	6.1	3.9
70/30 blend	0.0	0.0	0.0	10.1	3.4	0.0	6.0	14.1	6.7	0.0	7.8	15.1	7.6	0.9	12.4	11.0	8.1
50/50 blend	0.0	11.7	19.1	10.6	13.8	2.4	11.3	15.0	9.5	0.0	8.0	9.5	5.8	8.5	11.6	14.2	11.4
Mean	0.0	3.9	6.4	8.8	6.4	0.8	5.7	10.2	5.6	0.0	7.0	11.3	6.1	3.1	9.8	10.4	7.8
THPC -urea-NH																	
100% cotton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	2.6	0.0	0.0	5.1	1.7
70/30 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	8.6	6.6	0.0	10.0	9.9	6.6
50/50 blend	0.0	0.0	0.0	2.5	0.8	0.0	0.0	18.3	6.1	0.0	6.4	7.6	4.7	0.0	12.8	10.2	7.7
Mean	0.0	0.0	0.0	0.8	0.3	0.0	0.0	6.1	2.0	0.0	5.8	8.0	4.6	0.0	7.6	8.4	5.3
THPOH -NH_3																	
100% cotton	0.0	2.8	5.3	8.9	5.7	3.4	5.6	7.6	5.5	1.3	7.6	6.5	5.1	3.3	5.3	6.6	5.0
70/30 blend	0.0	1.7	7.3	6.7	5.2	0.5	2.0	9.1	3.9	3.1	11.8	14.0	9.6	2.0	13.5	9.3	8.3
50/50 blend	0.0	7.6	12.3	10.5	10.1	7.6	6.2	9.1	7.6	6.4	5.2	6.8	6.1	9.0	6.5	7.2	7.6
Mean	0.0	4.0	8.3	8.7	7.0	3.8	4.6	8.6	5.7	3.6	8.2	9.1	6.9	4.8	8.4	7.7	6.9

APPENDIX A

Mean Afterflame Time in Seconds of Unfinished and Flame-Retardant Finished Fabrics Before and After Laundering

Fabric and Finish	Unlaundered	Laundry A								Laundry B							
		Dry fold				Ironing treatment				Dry fold				Ironing treatment			
		5	10	20	Mean	5	10	20	Mean	5	10	20	Mean	5	10	20	Mean
Unfinished																	
100% cotton	8.7	10.1	7.7	10.4	9.4	8.5	7.0	10.3	8.6	6.7	5.9	7.3	6.6	9.4	8.1	9.4	9.0
70/30 blend	7.7	12.2	10.5	10.6	11.1	11.1	11.1	10.5	10.9	10.7	9.9	11.3	10.6	10.5	10.1	11.9	10.8
50/50 blend	9.3	8.5	6.7	15.5	10.2	9.0	9.0	11.7	9.9	6.9	7.8	6.7	7.1	8.8	7.4	9.2	8.4
Mean	8.5	10.3	8.3	12.1	10.2	9.5	9.0	10.8	9.8	8.1	7.8	8.4	8.1	9.6	8.5	10.1	9.4
APO-THPC																	
100% cotton	0.0	0.0	0.0	5.8	1.9	0.0	0.0	1.5	0.5	0.0	5.3	9.4	4.9	0.0	5.6	6.1	3.9
70/30 blend	0.0	0.0	0.0	10.1	3.4	0.0	6.0	14.1	6.7	0.0	7.8	15.1	7.6	0.9	12.4	11.0	8.1
50/50 blend	0.0	11.7	19.1	10.6	13.8	2.4	11.3	15.0	9.5	0.0	8.0	9.5	5.8	8.5	11.6	14.2	11.4
Mean	0.0	3.9	6.4	8.8	6.4	0.8	5.7	10.2	5.6	0.0	7.0	11.3	6.1	3.1	9.8	10.4	7.8
THPC -urea-NM																	
100% cotton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	2.6	0.0	0.0	5.1	1.7
70/30 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	8.6	6.6	0.0	10.0	9.9	6.6
50/50 blend	0.0	0.0	0.0	2.5	0.8	0.0	0.0	18.3	6.1	0.0	6.4	7.6	4.7	0.0	12.8	10.2	7.7
Mean	0.0	0.0	0.0	0.8	0.3	0.0	0.0	6.1	2.0	0.0	5.8	8.0	4.6	0.0	7.6	8.4	5.3
THPOH -NH_3																	
100% cotton	0.0	2.8	5.3	8.9	5.7	3.4	5.6	7.6	5.5	1.3	7.6	6.5	5.1	3.3	5.3	6.6	5.0
70/30 blend	0.0	1.7	7.3	6.7	5.2	0.5	2.0	9.1	3.9	3.1	11.8	14.0	9.6	2.0	13.5	9.3	8.3
50/50 blend	0.0	7.6	12.3	10.5	10.1	7.6	6.2	9.1	7.6	6.4	5.2	6.8	6.1	9.0	6.5	7.2	7.6
Mean	0.0	4.0	8.3	8.7	7.0	3.8	4.6	8.6	5.7	3.6	8.2	9.1	6.9	4.8	8.4	7.7	6.9

APPENDIX B

APPENDIX B

Mean Afterglow Time in Seconds of Unfinished and Flame-Retardant Finished Fabrics Before and After Laundering

Fabric and Finish	Unlaundered	Laundry A								Laundry B							
		Dry fold				Ironing treatment				Dry fold				Ironing treatment			
		5	10	20	Mean	5	10	20	Mean	5	10	20	Mean	5	10	20	Mean
Unfinished																	
100% cotton	8.6	15.5	18.3	13.3	15.9	13.9	22.4	7.9	14.7	18.3	10.6	10.3	13.1	9.3	15.9	17.3	14.4
70/30 blend	9.3	1.2	2.0	11.4	4.9	1.9	3.3	7.4	4.2	1.2	0.8	3.4	1.8	2.1	1.2	2.0	1.7
50/50 blend	0.6	0.0	0.2	0.8	0.3	0.0	0.0	0.6	0.2	0.0	0.5	1.1	0.5	1.2	0.2	0.0	0.5
Mean	9.5	5.5	7.0	8.5	7.0	7.2	8.6	5.3	6.4	6.5	4.0	4.9	5.1	4.2	5.8	6.6	5.5
APO- THPC																	
100% cotton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
70/30 blend	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
50/50 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
THPC -urea-NH																	
100% cotton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70/30 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
50/50 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
THPOH -NH_3																	
100% cotton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.2	8.4	8.5	0.0	12.2	13.3	8.5
70/30 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	6.2	2.4	0.0	1.2	9.8	3.6
50/50 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.2	0.0	0.3	0.5	0.3
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	5.1	3.7	0.0	4.6	7.8	4.2

APPENDIX C

APPENDIX C

Mean Char Length in Inches of Unfinished and Flame-Retardant Finished Fabrics Before and After Laundering

Fabric and Finish	Unlaundered	Laundry A								Laundry B							
		Dry fold				Ironing treatment				Dry fold				Ironing treatment			
		5	10	20	Mean	5	10	20	Mean	5	10	20	Mean	5	10	20	Mean
Unfinished																	
100% cotton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70/30 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50/50 blend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
APO - THPC																	
100% cotton	4.4	4.9	8.0	10.0	7.6	5.2	5.2	10.0	6.8	4.3	10.0	10.0	8.1	4.8	10.0	10.0	8.3
70/30 blend	6.3	8.9	9.6	10.0	9.5	9.4	10.0	10.0	9.8	8.0	10.0	10.0	9.3	9.9	10.0	10.0	10.0
50/50 blend	6.6	10.0	10.0	10.0	10.0	9.8	10.0	10.0	9.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Mean	5.8	7.9	9.2	10.0	9.0	8.1	8.4	10.0	8.8	7.4	10.0	10.0	9.1	8.2	10.0	10.0	9.4
THPC-urea-NH																	
100% cotton	5.0	4.5	3.8	4.8	4.4	4.1	4.1	4.3	4.2	4.3	9.0	10.0	7.8	4.1	7.1	10.0	7.1
70/30 blend	6.6	5.5	5.6	6.9	6.0	6.6	6.2	7.4	6.7	6.6	10.0	10.0	8.9	6.5	10.0	10.0	8.8
50/50 blend	5.7	7.1	7.2	9.9	8.1	6.9	8.3	10.0	8.4	8.5	10.0	10.0	9.5	7.7	10.0	10.0	9.2
Mean	5.8	5.7	5.5	7.2	6.1	5.9	6.2	7.2	6.4	6.5	9.7	10.0	8.7	6.1	9.0	10.0	8.4
THPOH-NH_3																	
100% cotton	5.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	0.0	3.3	10.0	0.0	0.0	3.3
70/30 blend	7.6	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	0.0	3.3	10.0	0.0	0.0	3.3
50/50 blend	9.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	0.0	3.3	10.0	0.0	0.0	3.3
Mean	7.7	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	0.0	3.3	10.0	0.0	0.0	3.3